This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

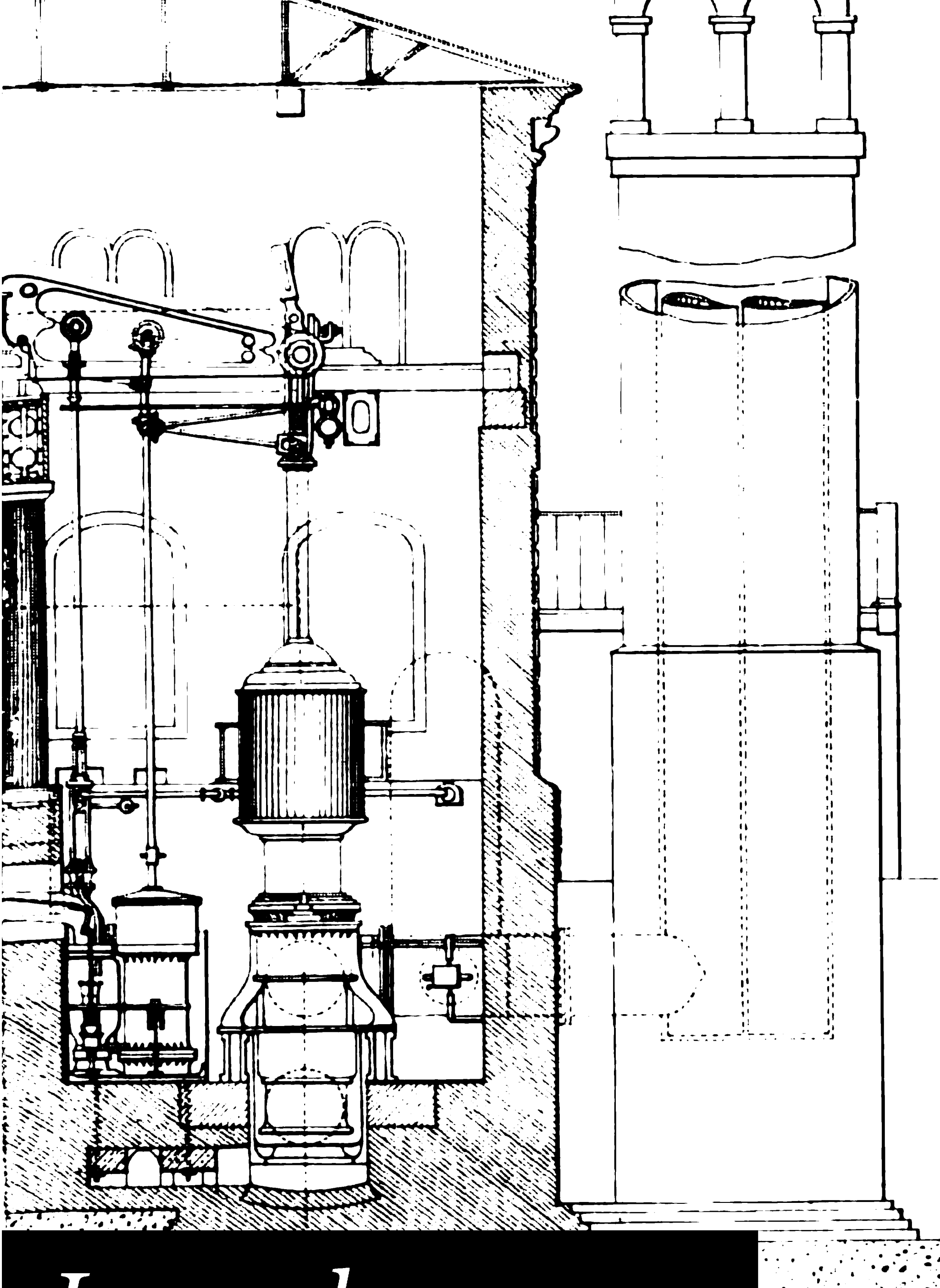
Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.
+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.
+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.
+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at http://books.google.com/



Journal

Society of Engineers (London, England)

Digitized by Google

U.C. BERKELEY
ENGINEERING LIBRARY

Digitized by Google

Digitized by Google

Digitized by Google

Digitized by Google

SOCIETY OF ENGINEERS.

MECHANICS' INSTITUTE SAN FRANCISCO.

ESTABLISHED MAY, 1854.

TRANSACTIONS FOR 1864.

PLACE OF MEETING, LOWER HALL, EXETER HALL, STRAND.

LONDON:
E. & F. N. SPON, 16, BUCKLERSBURY.
1865.

Digitized by Google

Digitized by Google

TA1
S67
1864
★★
Engineering
Library

PREMIUMS FOR 1864.

At the Meeting of the Society on January 16th, 1865, Premiums of Books were awarded to:—

MATHEW PARKES, for his Paper "On the Road Bridges of the Charing-Cross Railway."

BALDWIN LATHAM, for his Papers "On the Supply of Water to Towns."

VAUGHAN PENDRED, for his Paper "On Elastic Railway Wheels."

93574

Digitized by Google

Digitized by Google

CONTENTS.

Digitized by Google

Digitized by Google

LIBRARY OF THE UNIVERSITY OF CALIFORNIA

TRANSACTIONS, &c.

January 18*th*, 1864.

C. L. LIGHT IN THE CHAIR.

ON FUEL.

By PERRY F. NURSEY.

WHATEVER interest or importance attaches to the consideration of the subject of fuel under ordinary circumstances, that interest deepens and becomes very special when the subject is investigated in relation to those branches of engineering which have immediate reference to its employment as a source of mechanical power. Notwithstanding the splendid perfectness to which the science of mechanical engineering has attained, it is indisputable that there yet exists too great a discrepancy between the theoretical and the practical value of power. It may be said that all has been done that can be, in the construction of engines, with the view to economise fuel, and important indeed are the results which have accrued; but all has not yet been done, and although the mind cannot conceive where further improvement shall take place in mechanism, save in the application of existing principles, still it readily recognises the fact that there is an absence of that economy which ought to accompany the production of motive power under existing conditions.

Although it appears incredible that one pound of coal should produce an effect equal to raising a weight of a million of pounds one foot high, yet science has successfully demonstrated the fact that the mechanical energy contained in one pound of coal, and liberated by combustion, is capable of raising to the same height ten times that weight. But where is this ever realised? The results of some high-class engines have certainly reached, or even exceeded, the limit of a million pounds raised a foot high per pound of coal; but, taking the various classes of engines now in use, the average effect falls very far below that standard, possibly not reaching higher than one-third of that amount.

Since, therefore, machinery may be considered for all practical purposes as perfect, and since economy has been carried to the

Digitized by Google

utmost limit without the known contained power of coal as a fuel being more than partially utilised, the natural inference appears to be that a larger amount of consideration must be given to the nature and properties of fuel than it has hitherto received, and that some portion of the vast mental energy hitherto expended upon the adaptation of machinery to fuel is plainly demanded in the adaptation of fuel to machinery. The question is young, but not unimportant, and very closely allied with this is that of the duration of our English coal-fields. The annual yield of the British coal-mines has been almost trebled during the last twenty years, and has probably increased tenfold since the early part of the present century, owing to the introduction of railways and steam navigation, and the consequent development of manufactures. It is not probable that this increase will continue to advance in the same ratio; but we cannot contemplate, without anxiety, the rapid rate at which we are expending our best and most easily worked coal seams. According to statistics, collected by Mr. Hunt, of the Mining Records Office, the quantity of coal raised in the United Kingdom had, at the end of the year 1861, reached the enormous total of 86,000,000 tons; and, in the eight preceding years, the average annual increase amounted to $2\frac{3}{4}$ millions of tons. It has been estimated that, even at this moderate rate of increase, our coal seams would be exhausted in two hundred and twelve years. At the present rate of consumption, about nine hundred and thirty years would be their probable duration. These estimates are based upon the following data:—By taking the known thickness of the various workable seams of coal, and the area they extend over, the quantity in our coal-bearing strata is approximately arrived at. Assuming 4000 ft. to be the greatest depth to which mining operations can ever be carried, and rejecting all seams of less thickness than 2 ft., it is found that the total quantity of available coal in the British islands is about 80,000 millions of tons.

Seeing, then, that our coal-fields are not inexhaustible, and that a very moderate increase in the annual consumption places the limit of their duration at no very remote period, it becomes necessary to consider most carefully, not only how to economise that supply which we at present can call our own, but to produce an artificial fuel which shall satisfactorily occupy its position, as well now as when our coal-fields cease to yield; for, although this may not happen in our day, it will be well for this age if a coming generation shall have to acknowledge so rich a legacy as this would prove to be.

The fact has not been disregarded that Great Britain does not stand alone as a coal-producing country; on the contrary, it is remembered that the great quantity of coal which has been stored

Digitized by Google

up through remote ages in all parts of the world will probably be found sufficient to serve the purposes of its inhabitants for thousands of years. But much of England's greatness depends upon the superiority and cheapness of her coal over that of other nations, and this source of her wealth is rapidly diminishing, without hope of reproduction, for that phase of the earth's existence favourable to the formation of coal appears to have passed away for ever. It is evident, too, that at no distant date we shall labour under the disadvantage of increased cost of working, and, possibly, diminished value of produce. The United States of America can boast of coal-fields nearly forty times as extensive as ours. They, and other nations, will be working more accessible beds at less cost, and will consequently be able successfully to compete with English coal in every market.

The limits of a paper like the present prohibit such an elaboration of details as is consistent with the merits of the subject. It can only pretend to treat generally the natures and properties of various kinds of fuel, both natural and artificial, and to embody the well-authenticated results of such investigations as have been made with a view of ascertaining their economic values, their comparative evaporative powers, and their theoretical and actual duty. Following out these views, it is proposed to consider successively coal, coke, peat, and compound or patent fuels.

"What is the power that drives a railway train?" once asked George Stephenson, and receiving no satisfactory answer, he replied: "The light of the sun—light bottled up in the earth for tens of thousands of years—light absorbed by plants and vegetables, being necessary for the condensation of carbon during the process of their growth, if it be not carbon in another form, and now, after being buried in the earth for long ages in fields of coal, that latent light is again brought forth and liberated, made to work, as in the locomotive, for great human purposes." The philosophical mind of George Stephenson, unaided by theoretical knowledge, rightly saw that coal was the embodiment of power originally derived from the sun. That small pencil of solar radiation which is arrested by our planet, and which constitutes less than the two thousand millionth part of the total energy sent forth from the sun, must be regarded as the power which enabled the plants of the carboniferous period to wrest the carbon they required from the oxygen with which it was combined, and eventually to deposit it as the solid material of coal. In our day the reunion of that carbon with oxygen restores the energy expended in the former process, and thus we are enabled to utilise the power originally derived from the luminous centre of our planetary system.

Whatever has been predicated respecting the eternity of

Digitized by Google

matter, may also be predicated as to the eternity of power. It is the animating principle of the universe, and heat, electricity, and other natural agents are the vehicles through which it operates, or the forms which it assumes. The immediate source of most of the mechanical power existing in this planet is the sun. It is the sun which causes the winds to blow and which exhales the vapours, which, being afterwards precipitated as rain, nourish rivers and waterfalls. The sun also has accumulated the stores of mechanical power lying latent in our coal mines, and some portion of which is utilised by our steam engines. By the aid of the sun's rays vegetation is enabled to decompose the carbonic acid of the atmosphere and appropriate the carbon for its own nourishment and growth, and this carbon, by its subsequent combination with oxygen during combustion, produces the heat from whence we derive our power. There is every reason to believe that the mechanical value of the luminiferous vibrations by which carbonic acid is decomposed is equal to that of the resulting carbon when it is again consumed, and on this assumption it is possible, if we know the velocity of the luminiferous vibrations, to determine the density of the ether in which the vibrations are made.

The coal deposits may, therefore, be regarded as vast magazines of power, stored up at periods immeasurably distant for man's use. The principle of conservation of force, and the relationship now established between heat and motion, enable us to trace back the effects which we now derive from coal to equivalent agencies exercised at the period of its formation.

The several varieties of coal may, for the most part, be arranged into two groups: the one containing no bitumen, and the other distinguished by the presence of that substance. In the first variety, or that without bitumen, is anthracite, or glance coal, which is compact and hard, with a high lustre. Its specific gravity varies from 1.3 to 1.75, and it contains from 80 to 90 per cent. of carbon, with from 4 to 7 of water. In some varieties of anthracite bitumen is present; indeed, anthracite passes gradually into the second class or bituminous coal, the recognised varieties of which are:—Caking or pitching coal, which breaks into small pieces when heated, but on raising the heat they unite or cake into a solid mass; cherry coal, which resembles caking coal, but does not soften, being very brittle; splint or hard coal of the Glasgow beds, which is harder than cherry coal; and *cannel*, or candle, coal, which burns readily without melting, and has been used as *candles*, whence its name. It is of compact and even texture, and possesses but little lustre.

Liebig's views of the chemical processes which attend the formation of coal from wood may be thus summed up:—When wood is exposed to air and moisture it suffers decay, it moulders

Digitized by Google

and becomes gradually converted into a dark brown or black powder, called *mould* or *humus*. The longer the process has been continued the greater is the proportion of carbon in the residue. Thus oak wood is composed of $C_{36}\ H_{22}\ O_{22}$, and one specimen of oak humus was found to contain $C_{35}\ H_{20}\ O_{20}$, and another $C_{34}\ H_{18}\ O_{18}$, showing that for every two equivalents of hydrogen oxydised by the air, one equivalent of carbonic acid had been separated. If the decay were to continue until all the hydrogen had been separated, wood consisting of $C_{36}\ H_{22}\ O_{22}$, would leave only C_{25}; but this final result does not usually occur, because the excess of carbon retains the last portions of hydrogen with an increasing affinity as the amount of hydrogen diminishes.

When wood is decomposed by the action of water, air being absent, the process is more properly mouldering, for, in eremacausis, or decay, oxygen is the active agent. In mouldering, the access of oxygen is very limited, and the results are different from those of decay. The elements of water, together with some oxygen, are taken up and carbonic acid escapes. Thus when oak wood was decomposed by lying under water, a white mouldered matter was formed, containing $C_{33}\ H_{27}\ O_{24}$, and derived from oak wood $C_{36}\ H_{22}\ O_{22}$ by the addition of $5\ H\ O+O$, and the subtraction of $3\ C\ O_2$. Mouldered beech yielded $C_{33}\ H_{25}\ O_{24}$, which may be similarly accounted for. Wood coal, or brown coal, has been produced by a similar action. In the formation of wood coal the essential change seems to be the separation of carbonic acid from its elements, while a portion of hydrogen is removed by oxidation, owing to the limited access of air. The separation of carbonic acid seems still to go on even in the deepest beds of brown coal, and is probably the source of the acidulous springs found near such beds, and also of choke-damp in mines. When near the surface the proportion of hydrogen in wood coal is always less, owing to the action of the air, by the oxygen of which the hydrogen is removed.

Mineral coal appears to be produced by a long-continued decomposition of wood, or of wood coal, by which carbonic acid, water, and carburetted hydrogen are separated. Splint coal and cannel coal are both $C_{24}\ H_{13}\ O$, caking coal is $C_{20}\ H_9\ O$, or cannel coal minus olefiant gas $C_4\ H_4$. This explains the occurrence of fire-damp in coal mines; whereas in mines of wood coal carbonic acid, or choke-damp, alone occurs. The occurrence of fire-damp proves that changes are constantly occurring in the beds of coal. When the whole of the hydrogen is removed in the form of carburetted hydrogen, the residue must be anthracite, which is nearly pure carbon.

By distilling coal with water, oily and resinous matters have been obtained. These oils and naphtha may be formed out of

Digitized by Google

the elements of the carbonic acid and carburetted hydrogen, separated from the wood during its conversion into coal; but if the wood had been originally of the pine tribe, the resin and oil of turpentine may have been originally present in it.

Such, then, is an outline of the nature and chemical character of coal. Passing by the geological features of the coal measures, and the general economy of coal mining, we will proceed to notice the localities and extent of the principal coal tracks of Great Britain. These are variously dispersed in the midland, northern, and western portions of South Britain, and in a broad belt of country which traverses the centre of Scotland from the shores of Ayrshire to those of the Firth of Forth. There are also some coal tracks of inferior importance in Ireland. The following table affords some idea of the value of the coal of the British Islands:

TABLE of the Principal Coal-fields of the British Islands.

DISTRICT.	Estimated workable area in acres.	No. of workable seams.	Estimated total thickness of workable coal in feet.	Thickest bed in feet.	Thickness of coal-bearing measures in feet.
1. Northumberland and Durham.........	500,000	18	80	7	
2. Cumberland and Westmoreland, and West Riding of Yorkshire...........	99,500	42	20	20	2,000
3. Lancashire, Flintshire, and North Staffordshire...........................	550,000	104	227	29	6,200
4. Yorkshire, Nottinghamshire, Derbyshire....................................	651,500	12	32	10	
5. Shropshire and Worcestershire	88,950	23	40		
6. South Staffordshire.....................	65,000	11	67	40	1,000
7. Warwickshire and Leicestershire....	80,000	14	63	36	
8. Somersetshire and Gloucestershire...	167, 500	71	142	7	
9. South-Welsh coal-field..................	600,000	30	100	9	12,000
10. Scottish coal-fields......................	1,045,000	181	569	83	16,400
11. Irish coal-fields	1,850,000	17	63	6	

The coal-pits on the eastern side of the island occupy a large portion of the counties of Durham and Northumberland, and are the most important of all pits wrought for the sale of coal. In the Cumberland coal-field the pits are wrought only for sale. In the West Riding the pits supply extensive ironworks, as well as supplying part of Yorkshire with fuel, and also making shipments to London. The coal-fields of Lancashire extend southward into Cheshire, and are worked to an enormous extent for the supply of the manufactures in their neighbourhood. The great coal-fields of Derbyshire and Yorkshire commence in the vale of the Trent between Nottingham and Derby, extending northwards, and supplying with fuel a vast surrounding region,

Digitized by Google

as well as ironworks in their vicinity. The most important coal-field in the Midland Counties is that of South Staffordshire, which is remarkable for the extent to which its vast beds are worked for smelting iron ores, for the use of the neighbouring populous towns, and for the extensive supply of the surrounding country. The smaller district of Shropshire is also the seat of great ironworks, and supplies fuel for a great part of the vale of the Severn, and country to the west of it. The Warwickshire and Leicestershire coal-fields being without iron furnaces, are extensively wrought only for "land sale" or supply of surrounding parts, which extends through Bucks to the Thames. The Forest of Dean is a remarkable detached coal-field in Gloucestershire, in which pits are wrought for the manufacture of iron ores, and for a very extensive land sale. In North Somersetshire there are valuable mines. The most extensive coal-basin of the west is that of South Wales, which occupies considerable portions of Monmouthshire, Glamorgan, Carmarthen, and Pembroke. The internal consumption for smelting is enormous, and the supply to South Wales, Cornwall, part of Somersetshire, and even London.

The coal districts of the east of Scotland encircle the Firth of Forth in tracts of very irregular form, which occupy large portions of eight or nine counties. The coal is extensively wrought for land sale, for shipment, and for the Carron Ironworks. Lanarkshire, Ayrshire, and Renfrewshire, comprise nearly the whole of the irregularly scattered coal-fields of the west of Scotland, and their mines have been chiefly wrought for the supply of the great manufacturing population of which Glasgow is the centre.

The coal-fields of Ireland are comparatively unimportant; the principal are those of Castlecomer in Kilkenny, and the Queen's County. There are some pits worked in Tipperary, Dromagh, and Dysart in Cork, Drumglass and Coal Island in Tyrone, which, with the Arigua pits at the northern extremity of Roscommon, complete the list of Irish coal-mines in operation.

With regard to the comparative qualities of the various descriptions of coal, much valuable and important information will be found in the following elaborate tables of results obtained by Sir H. De la Beche and Dr. Lyon Playfair, in the experiments conducted by those gentlemen under instructions from the Admiralty, with a view of determining the most advantageous species of coal for steam navigation. Although the chief point of the investigation was the calorific powers of the different coals experimented on, yet the inquiry was not limited to this alone. Certain kinds of coal are more friable than others, some undergo a species of slow combustion, and in warm climates slack down like moistened lime. These qualities were examined, and the

Digitized by Google

whole was carefully discussed both in its scientific and practical aspects. One test of calorific efficacy was the quantity of litharge or oxide of lead which a given quantity of coal reduced to the metallic state. The amount of space coal requires for stowage was determined by its specific gravity and the nature of its fracture. It was found that a difference of as much as 20 per cent. existed between certain varieties of coal.

TABLE showing the Actual Duty, and that which is theoretically possible, of different Coals.

	Name or Locality of Coal.	Actual No. of lbs. of water converted into steam by 1 lb. of coal.—Practical.	Number of lbs. of water convertible into steam by the coke left by the coal.—Theoretical.	Number of lbs. of water convertible into steam by the carbon of the coal.—Theoretical.	Number of lbs. of water convertible into steam by the hydrogen of the coal.—Theoretical.	Total No. of lbs. of water convertible into steam by 1 lb. of coal.—Theoretical.
Welsh Coal.	Graigola	9. 35	11.301	11.660	1.903	13.563
	Anthracite (Jones and Co.)	9. 46	12.554	12.563	2.030	14.593
	Oldcastle Fiery Vein	8. 94	10.601	12.046	2.890	14.936
	Ward's Fiery Vein	9. 40	...	12.072	2.542	14.614
	Binea	9. 94	11.560	12.181	2.912	15.093
	Llangennech	8. 86	10.599	11·741	2.519	14.260
	Pentrepoth	8. 72	10.873	12.189	2.649	14.838
	Pentrefellin	6. 36	10.841	11.749	2.038	13.787
	Powell's Duffryn	10.149	11.134	12.126	2.966	15.092
	Mynydd Newydd	9. 52	9.831	11.463	3.441	14.904
	Three Quarter Rock Vein	8. 84	7.081	10.325	2.781	13.106
	Cwm Frood Rock Vein	8. 70	8.628	11.300	3.488	14.788
	Cwm Nanty-Gros	8. 42	8.243	10.767	3.165	13.932
	Resolven	9. 53	10.234	10.899	3.072	13.971
	Pontypool	7. 47	8.144	11.088	3.207	14.295
	Bedwas	9. 79	8.897	11.075	3.766	14.841
	Ebbw Vale	10. 21	10.441	12.335	3.300	15.635
	Porthmawr Rock Vein	7. 53	6.647	10.263	2.548	12.811
Scotch.	Coleshill	8. 00	6.468	10.145	2.654	12.799
	Dalkeith Jewel Seam	7. 08	6.239	10.242	2.071	12.313
	Dalkeith Coronation	7. 71	6.924	10.570	2.202	12.772
	Wallsend Elgin	8. 46	6.560	10.454	2.968	13.422
	Fordel Splint	7. 56	6.560	10.933	2.884	13.817
	Grangemouth	7. 40	7.292	10.970	2.722	13.692
Eng.	Broomhill	7. 30	7.711	11.225	3.638	14.863
	Park End Lydney	8. 52	6.567	10.101	3.156	13.257
	Slievardagh Irish	9. 85	10.895	10.995	1.487	12.482
	Formosa Island	...	...	10.752	2.841	13.553
	Borneo, Labuan Kind	...	...	8.864	1.388	10.252
	Do. 3ft seam	...	...	7.461	1.295	8.756
	Do. 11ft seam	...	...	9.652	1.948	11.600
	Wylam's Patent Fuel	8. 92	8.378	11.186	3.145	14.331
	Warlich's do.	10. 36	11.292	12.368	3.596	15.964
	Bell's do.	8. 53	9.168	12.074	3.343	15.417

Digitized by Google

TABLE showing the Actual Duty, &c.—*continued.*

	Name or Locality of Coal.	Actual force generated, or the No. of lbs. which 1 lb. of the coal could raise to the height of 1 ft., calculated from heat obtained.	Force capable of being generated, or No. of lbs. which could be raised to the height of 1 ft. by 1 lb. of coal—Theoretical.	Amount of ammonia corresponding to the nitrogen contained in coal.	Amount of sulphate of ammonia corresponding to the nitrogen contained in coal.
Welsh Coal.	Graigola	7,060,908	10,242,471	0.497	1.932
	Anthracite (Jones and Co.)	7,143,978	11,020,303	0.225	0.990
	Oldcastle Fiery Vein	6,751,285	11,279,329	1.590	6.175
	Ward's Fiery Vein	7,098,667	11,036,102	1.238	4.808
	Binea	7,506,463	11,397,892	1.586	6.741
	Llangennech	6,690,871	10,768,829	1.299	5.044
	Pentrepoth	6,585,146	11,205,322	0.218	0.848
	Pentrefellin	4,802,928	10,411,630	Trace	
	Powell's Duffryn	7,664,295	11,397,137	1.760	6.835
	Mynydd Newydd	7,189,288	11,255,163	1.808	7.340
	Three Quarter Rock Vein	6,675,768	9,897,355	1.299	5.044
	Cwm Frood Rock Vein	6,570,043	11,167,563	1.347	5.232
	Cwm Nanty-Gros	6,358,593	10,521,131	1.919	7.448
	Resolven	7,196,840	10,550,583	1.675	6.505
	Pontypool	5,641,175	10,795,260	1.639	6.364
	Bedwas	7,393,186	11,207,587	1.748	6.788
	Ebbw Vale	7,710,361	11,025,198	2.622	10.182
	Porthmawr Rock Vein	5,686,485	9,674,577	1.554	6.033
Scotch.	Coleshill	6,041,419	9,665,515	1.785	6.930
	Dalkeith Jewel Seam	5,346,655	9,298,499	1.214	0.471
	Dalkeith Coronation	5,822,417	9,645,125	Trace	
	Wallsend Elgin	6,388,800	13,135,991	1.712	6.647
	Fordel Splint	5,709,141	10,434,286	1.372	5.327
	Grangemouth	5,588,312	10,339.888	1.639	6.364
Eng.	Broomhill	5,512,795	11,224,201	2.234	8.674
	Park End Lydney	6,434,111	10,011,386	1.477	9.61[illegible]
	Slievardagh Irish	7,438,497	9,426,124	0.279	1.084
	Formosa Island	...	10,234,919	0.777	3.017
	Borneo, Labuan Kind	...	7,742,078	0.977	3.771
	Do. 3ft. Seam	...	6,612,333	1.132	4.620
	Do. 11ft. Seam	...	8,760,057	0.813	3.158
	Wylam's Patent Fuel	6,736,182	10,822,447	2.040	7.920
	Warlich's do.	7,823,634	12,055,635	Trace	
	Bell's do.	6,441,663	11,642,569	1.983	3.818

Digitized by Google

TABLE showing the Economic Value of different Coals.

	Names of Coal Employed in the Experiments.	Economical evaporating power of No. of lbs. of water evaporated from 212 deg. by 1 lb. of coal.	Weight of 1 cubic foot of the coal as used for fuel.	Weight of 1 cubic foot as calculated from the density.	Ratio of the economical to the theoretical weight.	Difference per cent. between the theoretical and economical weights.
			lbs.	lbs.		
Welsh Coal.	Graigola	9.35	60.166	81.107	.742	34.8
	Anthracite (Jones and Co.)	9.46	58.25	85.786	.679	47.26
	Oldcastle Fiery Vein	8.94	50.916	80.42	.633	57.946
	Ward's Fiery Vein	9.40	57.433	83.85	.685	46.
	Binea	9.94	57.08	81.357	.702	42.53
	Llangennech	8.86	56.93	81.85	.695	43.76
	Pentrepoth	8.72	57.72	81.73	.705	40.17
	Pentrefellin	6.36	66.166	84.726	.781	28.051
	Duffryn	10.14	53.22	82.72	.643	55.43
	Mynydd Newydd	9.52	56.33	81.73	.689	45.09
	Three Quarter Rock Vein	8.84	56.388	83.60	.674	48.26
	Cwm Frood Rock Vein	8.70	55.277	78.299	.706	41.648
	Cwm Nanty-gros	8.42	56.0	79.859	.701	42.60
	Resolven	9.53	58.66	82.354	.713	40.39
	Pontypool	7.47	55.7	82.35	.676	47.845
	Bedwas	9.79	50.5	82.6	.611	63.565
	Ebbw Vale	10.21	53.3	78.81	.676	45.98
	Porthmawr	7.53	53.0	86.722	.614	62.7
	Coleshill	8.00	53.0	80.483	.658	51.85
Scotch.	Dalkeith Jewel Seam	7.08	49.8	79.672	.625	59.984
	Do. Coronation Seam	7.71	51.66	78.611	.657	52.17
	Wallsend Elgin	8.46	54.6	78.611	.694	43.78
	Fordel Splint	7.56	55.0	78.611	.699	42.82
	Grangemouth	7.40	54.25	80.48	.674	48.35
Eng.	Broomhill	7.30	52.5	77.988	.673	48.55
	Sydney (Forest of Dean)	8.52	54.444	80.046	.68	47.02
	Slievardagh (Irish Anthracite)	9.85	62.8	99.57	.630	58.55
	Wylam's Patent Fuel	8.92	65.08	68.629	.948	5.45
	Warlich's	10.36	69.05	72.248	.955	4.49
	Bell's	8.53	65.3	71.124	.918	8.91

Digitized by Google

TABLE showing the Economic Value, &c.—*continued.*

	Names of Coal Employed in the Experiments.	Space occupied by 1 ton in cubic ft. (economic weight).	Results of experiments on cohesive power of coals, per centage of large coals.	Evaporating power of the coal after deducting for the combustible matter in the residue.	Weight of water evaporated from 212 deg. by 1 cubic foot of coal.	Rate of evaporation, or No. of lbs. of water evaporated per hour.—Mean.
Welsh Coal.	Graigola	37.23	49.3	9.66	581.20	441.48
	Anthracite (Jones and Co.)	38.45	68.5	9.7	565.02	409.37
	Oldcastle Fiery Vein	43.99	57.7	...	455.18	464.30
	Ward's Fiery Vein	39.	46.5	10.6	608.78	529.90
	Binea	39.24	51.2	10.3	587.92	486.95
	Llangennech	39.34	53.5	9.2	523.75	373.22
	Pentrepoth	38.80	46.5	8.98	518.32	381.50
	Pentrefellin	33.85	52.7	7.4	489.62	247.24
	Duffryn	42.09	56.2	11.80	540.12	409.32
	Mynydd Newydd	39.76	53.7	10.59	536.26	470.69
	Three Quarter Rock Vein	39.72	52.7	...	498.46	486.86
	Cwm Frood Rock Vein	40.52	72.5	9.35	480.90	379.80
	Cwm Nanty-gros	40.00	55.7	8.82	471.52	404.16
	Resolven	38.19	35.0	10.44	559.02	390.25
	Pontypool	40.216	57.5	8.04	416.07	250.40
	Bedwas	44.32	54.0	9.99	494.39	476.96
	Ebbw Vale	42.26	45.0	10.64	544.19	460.22
	Porthmawr	42.02	62.0	7.75	401.34	347.44
	Coleshill	42.26	62.	8.34	424.0	406.41
Scotch.	Dalkeith Jewel Seam	44.08	85.7	7.10	352.58	355.18
	Do. Coronation Seam	43.36	88.2	7.86	398.29	370.08
	Wallsend Elgin	41.02	64.	8.67	460.82	435.77
	Fordel Splint	40.72	63.	7.69	415.80	464.98
	Grangemouth	40.13	69.7	7.91	401.45	380.40
Eng.	Broomhill	42.67	65.7	7.66	383.25	397.78
	Sydney (Forest of Dean)	41.14	55.0	8.98	463.86	487.19
	Slievardagh (Irish Anthracite)	35.66	74.	10.49	618.58	473.18
	Wylam's Patent Fuel	34.41	...	9.74	580.51	418.89
	Warlich's " "	32.44	...	10.60	715.135	457.84
	Bell's " "	34.30	...	8.65	567.0	549.11

Digitized by Google

The evaporative powers of different coals in practice appear to be nearly proportional to the quantity of carbon they possess; bituminous coal is, therefore, less efficacious than coal consisting chiefly of pure carbon. A pound of the best Welsh or anthracite coal is capable of raising from 9½ lb. to 10 lb. of water from 212 deg. into steam, whereas a pound of the best Newcastle is incapable of raising more than about 8½ lb. of water from 212 deg. into steam, and inferior coal will not raise more than 6½ lb. into steam. Mr. Wicksteed gives the following table of the comparative evaporative powers of various coals when burned under boilers:

No.	Description of Coal.	Water evaporated per pound of coal.	Comparative cost per ton in London.
		lbs.	s. d.
1	The best Welsh	9.493	17 11
2	Anthracite	9.014	17 0
3	Best small Newcastle	8.524	16 1
4	Average small Newcastle	8.074	15 2¾
5	Average Welsh	8.045	15 2¼
6	Coke from gas-works	7.908	14 11
7	Coke and Newcastle small, ½ and ½	7.897	14 10¾
8	Welsh and Newcastle, mixed, ½ and ½	7.865	14 10
9	Derbyshire and small Newcastle, ½ and ½	7.710	14 6½
10	Average large Newcastle	7.658	14 5½
11	Derbyshire	6.772	12 9¼
12	Blythe Main Northumberland	6.600	12 5½

We will now proceed to the second division of the subject, coke, which, as is well known, is the residual carbon of pit coal after the volatile matters have been expelled by heat, it has a porous texture and a lustre sometimes approaching the metallic. It is a valuable fuel, producing an intense and steady heat, and leaving but little residue after combustion. As locomotives are prohibited from smoking, coals can only be used sparingly, coke is therefore generally employed in generating steam. This important item of expenditure appears to have received but little attention, for the ratios of quantity and heating power of coke to the coals from which it is made appear to be much the same as Smeaton found them more than a hundred years ago. In the report quoted, Sir H. De la Beche and Dr. Lyon Playfair remark that the whole system of coke manufacture is imperfect, inasmuch as it allows the loss of some valuable products, such as sulphate of ammonia, which is worth about 13*l.* per ton; a hundred tons of coke would give about six tons of this substance. There are also much heat and much hydrogen gas evolved during coking which are seldom turned to profitable use. In some iron-

Digitized by Google

works the gases escaping from the furnaces have been utilised. There is a considerable quantity of pure hydrogen produced by the decomposition of the water in cooling coke. It might be worth a trial to determine the commercial value of collecting such products from the coke furnaces.

The best process of manufacturing coke is still an open question, some engineers preferring hard, others soft-burnt coke. The general opinion inclines to hard coke, although reason would point to the soft as being the better fuel. The comparative term *hard* is understood to apply to coke from which all volatile matters have been expelled, while *soft* refers to coke in which a portion of these gases is left. They also apply to the same vertical piece of coke in the oven of which the upper part would be hard and little would be expelled by farther heat, whilst the lower part would be softer, and emit a gaseous flame on being heated farther. At the Par Consols Mine, the open burning coals are watered to give intensity to the heat of the furnace; this goes to prove that hydrogen gas is more valuable in generating steam than has been usually estimated. Some of the best locomotive drivers water their coke to make it last longer. Steam has been introduced into the furnace to promote economy of fuel. The result in each case is to introduce water in a finely-divided state into an intensely hot fire, which decomposes it into its equivalent of hydrogen and oxygen, and thus aids the evaporative powers of the fuel. Whatever benefit may be derived from such introduction of water arises from the gases evolved, and shows the desirability of retaining rather than expelling such gases in coking. A strong draught is required to promote the combustion of coke, but the least admission of air to spontaneously-ignited coal produces immediate conflagration. If, in coking, a considerable portion of these combustible qualities of coal could be retained, and the carbonaceous smoky portions only expelled, an obvious economy would result.

Digitized by Google

Table showing the Calorific Values of different Coals.

	Name of Coal.	Quantity of lead reduced by one part of coal.	Oxygen removed from litharge by one part of coal.	Quantity of oxygen theoretically required by carbon and hydrogen.	Quantity of oxygen required by carbon alone.	Relative calorific values, carbon taken as 100.	No. of lbs. of water which 1 lb. of coal can raise from 32° Fah. to 212° Fah.
Welsh.	Graigola	32.08	2.49	2.49	2.26	93.4	72.66
Welsh.	Anthracite (Jones and Aubrey)	33.48	2.60	2.69	2.43	97.5	75.73
Welsh.	Oldcastle Fiery Vein	81.42	2.44	2.71	2.34	91.5	71.16
Welsh.	Ward's Fiery Vein	31.46	2.44	2.65	2.34	91.5	71.25
Welsh.	Binea Coal	31.64	2.46	2.72	2.36	92.2	71.66
Welsh.	Llangennech	32.66	2.53	2.59	2.28	94.9	73.97
Welsh.	Pentrepoth	31.16	2.37	2.69	2.36	89.6	70.57
Welsh.	Pentrefellin	30.52	2.37	2.53	2.28	89.2	69.13
Welsh.	Powell's Duffryn	30.00	2.33	2.71	2.35	87.7	67.95
Welsh.	Mynydd Newydd	30.34	2.35	2.67	2.25	88.5	68.72
Welsh.	Three Quarter Rock Vein.	26.62	2.06	2.34	2.00	77.2	60.29
Welsh.	Cwm Frood Rock Vein	28.30	2.19	2.62	2.19	82.5	64.10
Welsh.	Cwm Nanty Gros	29.64	2.28	2.47	2.08	85.5	67.13
Welsh.	Resolven	32.16	2.50	2.49	2.11	93.7	72.84
Welsh.	Pontypool	27.46	2.13	2.55	2.15	80.2	62.19
Welsh.	Bedwas	28.20	2.19	2.60	2.15	82.1	63.87
Welsh.	Ebbw Vale	32.00	2.48	2.80	2.39	93.0	72.48
Welsh.	Porthmawr Rock Vein	24.78	1.92	2.33	1.99	72.0	56.12
Welsh.	Coleshill	26.14	2.03	2.28	1.96	76.1	59.21
Scotch.	Dalkeith Jewel Seam	26.42	2.05	2.24	1.98	76.8	59.84
Scotch.	„ Coronation Seam	24.56	1.96	2.32	2.05	73.5	55.63
Scotch.	Elgin Wallsend	29.06	2.25	2.38	2.02	84.7	65.82
Scotch.	Fordel Splint	29.00	2.25	2.47	2.12	84.7	65.68
Scotch.	Grangemouth	28.48	2.20	2.46	2.13	82.8	64.51
	Broomhill (English)	25.32	1.96	2.63	2.18	73.5	57.35
	Slievardagh (Irish)	30.10	2.33	2.31	2.13	87.7	70.44
	Wylam's Patent Fuel	28.82	2.23	2.52	2.13	84.0	65.27
	Bell's „	28.52	2.21	2.75	2.34	83.2	64.29
	Warlich's „	31.50	2.44	2.84	2.40	91.5	71.35

Table showing the Amount of various Substances produced by destructive Distillation of certain Coals.

Name of Coal.	Coke.	Tar.	Water.	Ammonia.	Carbonic acid.	Sulphuretted hydrogen.	Olefiant gas & hydro-carbon.	Other gases inflammable.
Graigola	85.50	1.20	3.10	0.17	2.79	traces	0.23	7.01
Anthracite (Jones, Aubrey, and Company)	92.90	none	2.87	0.20	0.06	0.04	...	3.93
Oldcastle Fiery Vein	79.80	58.6	3.39	0.35	0.44	0.12	0.27	9.77
Ward's Fiery Vein	...	1.80	3.01	0.24	1.80	0.21	0.21	
Binea	88.10	2.08	3.58	0.08	1.68	0.09	0.31	4.08
Llangennech	83.69	1.22	4.07	0.08	3.21	0.02	0.43	7.28

Digitized by Google

TABLE showing the Mean Composition of average Samples of the Coals.

	Locality or Name of the Coal.	Specific gravity of coal.	Carbon.	Hydrogen.	Nitrogen.	Sulphur.	Oxygen.	Ash.	Per centage of coke left by each coal.
Welsh.	Graigola	1.30	84.87	3.84	0.41	0.45	7.19	3.24	85.5
Welsh.	Anthracite	1.375	91.44	3.46	0.21	0.79	2.58	1.52	92.9
Welsh.	Oldcastle Fiery Vein	1.289	87.68	4.89	1.31	0.09	3.39	2.64	79.8
Welsh.	Ward's Fiery Vein	1.344	87.87	3.93	2.02	0.83	*	7.04	...
Welsh.	Binea Coal	1.304	88.66	4.63	1.43	0.33	1.03	3.96	88.10
Welsh.	Llangennech	1.312	85.46	4.20	1.07	0.29	2.44	6.54	83.69
Welsh.	Pentrepoth	1.31	88.72	4.50	0.18	...	3.24	3.36	82.5
Welsh.	Pentrefellin	1.358	85.52	3.72	trace	0.12	4.55	6.09	85.0
Welsh.	Duffryn	1.326	88.26	4.66	1.45	1.77	0.60	3.26	84.3
Welsh.	Mynydd Newydd	1.31	84.71	5.76	1.56	1.21	3.52	3.24	74.8
Welsh.	Three quarter Rock Vein	1.34	75.15	4.93	1.07	2.85	5.04	10.96	62.5
Welsh.	Cwm Frood Rock Vein	1.255	82.25	5.84	1.11	1.22	3.58	6.00	68.8
Welsh.	Cwm Nanty-Gros	1.28	78.36	5.59	1.86	3.01	5.58	5.60	65.6
Welsh.	Resolven	1.32	79.33	4.75	1.38	5.07	*	9.41	83.9
Welsh.	Pontypool	1.32	80.70	5.66	1.35	2.39	4.38	5.52	64.8
Welsh.	Bedwas	1.32	80.61	6.01	1.44	3.50	1.50	6.94	71.7
Welsh.	Ebbw Vale	1.275	89.78	5.15	2.16	1.02	0.39	1.50	77.5
Welsh.	Porthmawr Rock Vein	1.39	74.70	4.79	1.28	0.91	3.60	14.72	63.1
Welsh.	Coleshill	1.29	73.84	5.14	1.47	2.34	8.29	8.92	56.0
Scotch.	Dalkeith Jewel Seam	1.277	74.55	5.14	0.10	0.33	15.51	4.37	49.8
Scotch.	,, Coronation do.	1.316	76.94	5.20	trace	0.38	14.37	3.10	53.5
Scotch.	Wallsend Elgin	1.20	76.09	5.22	1.41	1.53	5.05	10.70	58.45
Scotch.	Fordel Splint	1.25	79.58	5.50	1.13	1.46	8.33	4.00	52.03
Scotch.	Grangemouth	1.29	79.85	5.28	1.35	1.42	8.58	3.52	56.6
Eng.	Broomhill	1.25	81.70	6.17	1.84	2.85	4.37	3.07	59.2
Eng.	Park End, Sydney	1.283	73.52	5.69	2.04	2.27	6.48	10.00	57.8
	Slievardagh (Irish)	1.59	80.03	2.30	0.23	6.76	*	10.80	90.1
	Formosa Island	1.24	78.26	5.70	0.64	0.49	10.95	3.96	...
	Borneo (Lubun Kind)	1.28	64.52	5.74	0.80	1.45	20.75	7.74	...
	Borneo, 3ft. Seam	1.37	54.31	5.03	0.98	1.14	24.22	14.32	...
	Borneo, 11ft. Seam	1.21	70.33	5.41	0.67	1.17	19.19	3.23	...
	Wylam's Patent Fuel	1.10	79.91	5.69	1.68	1.25	6.63	4.84	65.8
	Bell's do.	1.14	87.88	5.22	0.81	0.71	0.42	4.96	71.7
	Warlich's do.	1.15	90.02	5.56	trace	1.62	*	2.91	85.1

* Included in ash.

Some information was afforded upon the economy of hard and soft coke by the gauge contest, during which the least advantage of load, gradient, wind, or coke was carefully noted. The Newcastle or Durham coke, used chiefly on the northern railways, bore a high name for its evaporative powers and durability, whilst the Welsh coke used on the Great Western Railway had only a local character inferior to the northern coke, and a claim was made for an equivalent allowance for this supposed difference. Subsequently to these trials the question was practically tested on the broad gauge, and, contrary to anticipation, ended

Digitized by Google

in favour of the softer Welsh coke as regarded time and load with draughts suited to each variety, and of this coke the softer burnt was found to produce the best results. In one instance, when the power of a particular engine was tried, the more beautiful-looking upper parts of the coke were selected, and the trial proved a failure for want of steam. The rejected portion of the coke was used by an engine on ordinary duty, and produced a contrary result. But coke, like coal, varies considerably in its heating powers, and requires the draft and process of combustion to be carefully attended to. In the preceding tables is shown the per-centage of hard coke in different coals as determined by careful experiment.

At one time coke was made in heaps roughly covered from the air, but furnaces or ovens are now employed for that purpose. These ovens are of various forms, but it is not so much the form as the proper admission of air to the coking coals which is of importance. There is no great superiority in the most costly ovens over the cheaply-constructed circular oven with a well-regulated supply of air. This description of oven is shown in elevation, section, and plan in Fig. 1, Plate I. They usually hold from five to six tons of coal, and the air is admitted at the top of the doorway, which is finally closed as required, and luted with clay. The brick-built door is taken down when the process of coking is completed, and water is injected to cool down the coke, which is afterwards removed by the crane and shovel. Messrs. Cory, of London, use these ovens. They are erected in a group, and connected with a central chimney.

Church's circular ovens were on the same general plan, but with a series of air passages below the coke-bed, but not in contact with the coke. When the coking process was complete these passages were opened to admit a current of cold air to aid in cooling down the hot coke, which was effected by carefully excluding all air from the oven without the use of water. Coke so made was, therefore, perfectly dry, and free from hygrometric water (until it absorbed it from the atmosphere), and was in considerable repute for its steaming power. The plan of cooling with water is generally preferred, and when done in the oven there is a better return of large coke than when cooled outside the oven.

Cox's patent oven is arranged to make both coke and gas at the same time, as seen in Fig. 2, Plate I. The air is admitted by side passages passing along the brickwork and opening into the back of the oven. The air is thus heated before it comes near the coking coal, and passes by the flue to the chimney. For making gas a retort is placed in the upper arch, which is acted upon by the escaping heat of the oven. For coke alone,

Digitized by Google

the upper arches might be dispensed with, and the chimney placed at the front, which would reduce the cost of erection without impairing the coke. There are holes for observing the process of coking by the escaping products of combustion, and for increasing the draft when required. The coke is drawn out hot on a cradle, which is placed on the floor of the oven and the coals put in afterwards, which, when coked, are brought out in a mass.

The coke-ovens of the Bristol and Exeter Railway, at Bridgewater, embrace modifications of Church's and Cox's ovens. Church's cooling air passages are made to come in contact with the coke to promote equal ignition, and the side air passages have frequent openings into the oven, whilst the upper passages further regulate the admission of air. Fig. 3, Plate I., is a ground plan, and a plan, at air passages, of a set of eight of these ovens, communicating with a central chimney. The ground plan shows the lower side air passages leading from the front, and, by the transverse dotted passages underneath the coals, to promote equal ignition of the whole mass at once. When this is done these passages are closed for that occasion. The other plan is at the upper air passages, for regulating the supply to the burning fuel. The side openings introduce the air so as to distribute it as equally as possible above the burning mass. The spaces parallel with the chimney between the ovens are filled up with dry rubble. Fig. 4, Plate I., shows a transverse section, and a vertical section at the junction with chimney. Fig. 5, Plate I., shows a longitudinal section, and also a front elevation, with cast-iron doors and fittings. These ovens are worked in rotation so as to produce the required daily supply of coke. When the coke is cooled in the oven the fresh coals require to be lighted; but when the coke is drawn hot, the heat of the oven ignites the coals. The door is then lined inside with fire-bricks, and luted with clay; sometimes no door is used, the opening being built up with fire-bricks, air passages being left, which are closed as coking progresses.

The Bristol and Exeter ovens yield about 13 cwt. of good coke, 6½ cwt. of small and waste coke, and some ashes, fit for lime-burners, from 1 ton of Cardiff coals. The quantity of small is probably increased by the coke being drawn hot, when it is more friable. The Great Western Company use both costly and cheap ovens, and for all practical purposes find no difference, either in the quantity or quality of the products, so long as they are worked by careful burners.

At the Camden-town station of the North-Western Railway is a range of coke-ovens eighteen in number; they are erected in two lines on a bed of concrete, and the whole of them discharge their products of combustion into a horizontal flue, which termi-

Digitized by Google

nates in a chimney stalk 115 ft. high. The ovens are of the horse-shoe form in plan, each being 12 ft. × 11 ft. internally, and having walls 3 ft. thick. The flue is 2 ft. 6 in. high, and 1 ft. 9 in. wide; the chimney is 11 ft. internal diameter at flue level. The ovens are alternately charged with 3½ tons of good coals, a wisp of straw is thrown in on the top, and takes fire from the heat of the dome (retained from the preceding operation), and inflames the smoke produced by the reaction of the heated sides and bottom upon the fuel.

The coking advances slowly and regularly from the top of the heap to the bottom, one layer only being affected at a time, and the surface being covered with a stratum of red-hot cinders, which consume the gases escaping from below. After a calcination of about forty hours the coke is cooled down to moderate ignition, by sliding in the dampers and sliding up the doors which had been partially closed during the latter part of the process. It is now observed to form prismatic concretions, which are forthwith taken out and extinguished by water sprinkled on them. Good coals thus treated yield 80 per cent. of excellent coke, which weighs about 14 cwt. per chaldron.

In considering the next part of the subject, Peat, some little detail is observed. As the question is worth attention, care has been taken to obtain such authentic information as is afforded by the present limited use of peat as a fuel.

It is calculated the deposits of peat in Great Britain and Ireland occupy an area of not less than six million acres. In Ireland these deposits are commonly called bogs; in Scotland, mosses; and in England, moors and heaths. But though differently denominated, they are all similar in character, being composed chiefly of vegetable matter, wholly or partially decomposed, and retaining a large quantity of water.

The peat near the surface is generally of a light colour, and spongy or stringy; it becomes browner and more dense at a greater depth; and quite black towards the bottom of the deposit, where it is sometimes hard and solid. The thickness of peat varies in different localities from 2 ft. to 40 or 50 ft. Assuming the average thickness to be only 12 ft., an acre would yield about 3500 tons of dried peat; consequently, the aggregate estimated acreage in this country would produce 21,000 million tons of dried peat, equal to the supply of 21,000,000 tons per annum for a thousand years. It cannot be supposed that these enormous masses of vegetable matter were created to be either useless or noxious; nor is it a matter for wonder that attention has often been directed, both in this country and others where similar deposits exist, to the means of utilising the peat and reclaiming the land which it covers.

Digitized by Google

The use of peat as a fuel was formerly more common in this country than at present, the introduction of canals and railways in modern times having afforded facilities for the transport of coal for a long distance at a small cost. In several foreign countries, where coal is more scarce or less accessible than in England, peat is more generally consumed; but there are still some isolated parts of Great Britain where peat is the principal or only fuel; and in Ireland it is more extensively used, in consequence of the dearness of coal. With a few small exceptions, peat is not an article of commerce in this country, but it is consumed in winter by those who cut and dry it in the summer. The value of peat, when properly dried, is well known and admitted, both for domestic fuel and for generating steam; and charcoal, properly made from such peat, is, in all respects, equal, if not superior, to wood charcoal.

Peat, when dug from the bog, generally contains from 50 to 75 per cent. of water. The difficulty of getting rid of so much moisture has caused a preference to be given to the uppermost portion of the deposit, which abounds most with roots and coarse fibres, and parts most readily with the water not actually shut up within those fibres. In this condition it produces an inferior fuel, which will not withstand the blast, and makes an imperfect charcoal.

The abundance of peat and the paucity of other fuel in Ireland, together with the poverty and distress in that country in 1846, originated a benevolent scheme for employing the destitute population in the preparation of charcoal for home consumption, and of peat charcoal for exportation to the great iron-works in England and Scotland. A large capital was raised and liberal profits were anticipated, but never realised. Though wages were very low, the time and labour occupied in cutting the turf and drying it entailed a cost which left no margin for profit. It was found that the air-dried peat, at the end of several months after the turf was cut, contained from 25 to 30 per cent. of moisture, the dispelling of which left a comparatively small part of the bulk for serviceable ignition. This led to the invention of machines for expelling the water from the peat by centrifugal force, and of consolidating the peat so dried by hydraulic pressure. A superior article was thus produced, but the cost of the machinery and the power requisite to work it prevented the manufacture from being remunerative. Ingenuity and skill were also exercised in extracting valuable products from peat—viz. naptha, paraffin, volatile oil, acetate, and carbonate of ammonia, &c. The paraffin was converted into candles superior to those made of wax; but here again the apparatus and the processes were too costly to be profitable. The notoriety of this scheme and of its failure did

Digitized by Google

much to check subsequent attempts in the same direction, and but little has been done until very recently towards the fulfilment of the oft-repeated prediction, that our bogs will become sources of eminently productive industry, and that the waste land which they cover will be reclaimed for profitable cultivation.

The inference to be drawn from experience is that, to insure commercial success in utilising peat, the operation must be inexpensive and expeditious; and costly machinery must be avoided. To produce a perfect article the coarse roots must be removed, and the smaller fibres broken up; these objects are accomplished by the simple invention which has been patented by Mr. Buckland, and which was to be seen in operation at the International Exhibition of 1862. The article prepared by this process is called condensed peat, in contradistinction to compressed peat.

The process of manufacture is as follows (see Fig. 6, Sheet I.): Immediately the peat is dug from the bog it is thrown or tipped into a hopper, beneath which is a strainer, formed of perforated metal, and within the strainer is an Archimedean screw. At the bottom of the strainer is a small opening, through which any very coarse, undecomposed roots and fibres which will not pass through the perforations of the strainer fall into a waste pipe and are rejected, or may be used for any purpose not requiring superior fuel. By turning the screw within the strainer the small fibres are cut up by the sharp edges of the perforated metal, through which they pass with the decomposed part of the peat, with which they thus become assimilated. A strainer of two feet in diameter with perforation of one-eighth of an inch diameter, and fifteen to the square inch, contains about 12,000 holes, which are equal to an aggregate aperture of a square foot: a strainer of this size will discharge about eight tons of peat per hour, or nearly one hundred tons in twelve hours. The decomposed peat protrudes through every hole in the strainer, and drops, in vermicular forms, upon an endless band which delivers the strained peat into a brick machine, which will mould in any suitable shape or size. The operation of moulding the peat into one of Clayton's small brick machines was to be seen in the International Exhibition. The strainer being enclosed in a heated chamber, with an opening for the escape of steam, the moisture is rapidly driven off from the worm-like strings as they fall upon the band, giving solidity to the mould blocks of peat as they pass through the die of the brick machine, and their being then at high temperature, expedites the subsequent process of drying. Very little power is required for the whole operation, which is performed continually and with great rapidity. The moulded blocks of peat are removed to a drying shed, through which a current of hot, moist air passes, and they soon, without

Digitized by Google

compression, become as hard as oak, and more dense than any peat submitted to hydraulic pressure, the specific gravity being from 1.15 to 1.50, and that of highly compressed peat 1.08. From four to five tons of wet peat, as taken from the bog, are required to make one ton of dry condensive peat, the total cost of which necessarily varies in different localities; but it may be safely assumed that the average cost will not exceed that of coal at the pit's mouth. Peat thus prepared burns very freely, will stand a powerful blast, emits great heat, is smokeless, and produces less ash than the average of coal or coke. It is impervious to water, improves by keeping, and is incapable of self-ignition. From two and a half to three tons of prepared peat will make one ton of excellent charcoal according to the degree of carbonisation required, the cost of which would be about 10s. per ton; but in converting the peat into charcoal, 1 cwt. of hydrocarbon or peat tar may be drawn from one ton of peat, the value of which, for illuminating and lubricating purposes, will greatly reduce, if not entirely cover, the cost of the charcoal.

The general heating power of the condensed peat is very superior to that of coal. The following is a tabulated statement of some experiments made by Messrs. Jackson and Townson, with the view of ascertaining the comparative boiling, evaporating, and fusing properties of condensed peat and coal. Five samples of peat and one of coal were tried, the same quantity of each in weight being used:

Fuel.	Time in which the same body of water was brought to boiling point.	Time in which the same body of water was evaporated.	Time in which complete fusion was effected.
Coal (good furnace)	6 minutes.	14 minutes.	31 minutes.
Peat No. 1..................	1½ „	6 „	14 „
„ 2............	1 „	7 „	17 „
„ 3.................	1 „	7 „	26 „
„ 4.................	1 „	6 „	17½ „
„ 5.................	1 „	5 „	11 „

It will be observed that No. 5 possesses a remarkable degree of heating power; its durability is also much greater than that of the other four samples. All the samples were produced from the same bog, and were of fair average quality, but had been submitted to different degrees of heat in drying, so that the difference in their results was due to the mode of treatment and not to any difference in the quality of the peat. The duration of the fuel after ignition was the same with the coal as with an equal weight of the No. 5 sample of peat. The duration of the other samples of peat was one-third less than that of the coal.

The condensed peat appears very well adapted for steam-

Digitized by Google

engines, whether marine, stationary, or locomotive, inasmuch as its use has been found to effect a saving of fifty per cent. in time in generating steam, and it will do double duty as compared with coal. The absence of smoke and of clinkers, and the preservation of fire-bars and boilers from the destructive effects of the sulphur in coal, are additional and important advantages. In a trial trip made by Mr. Fothergill with a river-boat using the condensed peat, the vessel was under steam 2 h. 20 min., during which time the total quantity consumed was exactly 12 cwt. The average consumption of coals for a similar trip was 12 cwt. per hour. In this instance the fire-bars, being of the ordinary description, were too wide apart for peat, and thus the full effect of the fuel was not obtained, as some portion passed through only partially consumed. There was no smoke, nor was there any deposit of clinker on the fire-bars—two valuable properties.

Mr. Yorston, the locomotive engineer of the Belfast and Northern Counties Railway; Mr. Stephenson, engineer of the Ulster Railway; and Mr. Domville, engineer of the Belfast and County Down Railway, superintended a trial of the condensed peat on the Belfast and Northern Counties Railway, with the view of testing its qualities as a fuel for locomotives. The trip was made from Carrick Junction to Ballymena, a distance of twenty-seven miles. During the whole of the journey there was an excess of steam, although the fire-door was kept constantly open, and the damper down, for the greater portion of the distance. The pressure at starting was 100 lb. per square inch. The commencement of the journey was up an incline of 1 in 80, four miles long, and with double curves; while ascending the incline the pressure rose to 110 lb., and afterwards to 120 lb., and this with the fire-door open. The speed was about forty miles per hour. While on the way the fuel emitted no smoke, and very little when at stations. The fire-box was examined at Ballymena, and a very small portion of clinker was found. The smoke-box was perfectly free from cinders or dust, a proof that the fuel had stood the blast exceedingly well, and it was the recorded opinion of the experimenters that the condensed peat was in every way well adapted as a fuel for locomotive purposes.

The following are the particulars of the foregoing locomotive trial of condensed peat fuel:

Digitized by Google

Total quantity of fuel used	14 cwt. 1 qr. 14 lb.
Weight of train, including engine and tender	70 tons.
Number of carriages	7.
Miles run	74.*
Time running	3 hours and 9 min.
Weight, per mile, used of peat fuel	21.47 lb.
Average lbs., per mile, for three months, using Welsh and Scotch coals, at a ratio of two of Welsh to one of Scotch	25.25 lbs.
Average for one mouth	26.29 lbs.

(Signed) A. YORSTON, Locomotive Engineer.

*Actual distance	64 miles.
Allowed for the 1 hour and 35 min. time engine was standing after getting up steam, and before starting	10
	74

The condensed peat has been proved by assay to contain but a trace of sulphur, and to be entirely free from phosphorus, thus offering great advantages over ordinary coal for smelting iron, and other purposes where the presence of either of those bodies is so notoriously pernicious. The following is the result of an assay, by Mr. Rickard, of the condensed peat:—

Moisture	2.00
Hydro-carbonaceous matter	67.00
Coke	30.97
Sulphur	0.03
Phosphorus	None.
	100.00

Ash, 2 per cent., consisting of lime, alumina, silica, and peroxide of iron.

The charcoal produced from condensed peat is very dense; its specific gravity is 1.75, being equal to that of the best ninety-six hour coke. Peat and peat charcoal may, therefore, be used in every stage of iron-making—beginning with the calcining of the ore, proceeding to the blast furnace, the cupola, the air furnace, the refining and puddling furnace, and ending with the reheating and annealing furnace. The value of charcoal iron in England is double that of iron made with coal or coke. A very small quantity of charcoal pig-iron is now made in this country, and English charcoal bar-iron is made from coke pig-iron, charcoal being used only in the subsequent stages of the manufacture. The largest consumption of charcoal bar made from coke pig is at the tin-plate works in England and Wales, requiring about 500 tons of charcoal per week, at a cost of 40s. to 50s. per ton. It is found that peat charcoal at the tin-plate works is equal to wood charcoal. Charcoal bar made from charcoal pig is used chiefly in England for the manufacture of steel, and is imported from

Digitized by Google

Sweden, Russia, and Germany. Mr. Mushet says:—"Peat charcoal contains a portion of vegetable carbon superior even to that contained in oak. The introduction of peat for the manufacture of iron in our age ought not to excite the same degree of wonder that Dudley's invention with pit coal did in the last century." According to Dr. Ure, "Turf charcoal is 20 per cent. more combustible than that of oak. Peat has been found preferable to all other fuel for case-hardening iron, tempering steel, forging horse-shoes, and welding gun-barrels."

The value of peat fuel for making iron has long been proved on the Continent. A report from Moscow—in the neighbourhood of which there are immense deposits of peat—states that one ton of peat gives as much heat as one and a half tons of deal wood. It has been found in Germany that an equal quantity of peat charcoal produces a greater quantity of iron from the ore than the best wood charcoal. In Bohemia and Bavaria, iron of the highest quality has been smelted, puddled, and re-heated, peat fuel alone being used in the entire manufacture. It is remarkable that peat abounds in close contiguity to iron ore, consequently the cost of transit may generally be saved when peat is used in the manufacture of iron. Mr. J. Bewick, in a treatise on the Cleveland Iron District, estimates the quantity of ironstone in North Yorkshire to be sufficient to supply two hundred blast furnaces for eight or nine hundred years. He adds:—"But where is the fuel to come from? The great coal-fields of Durham and Northumberland have been estimated to last between three and four hundred years only. This truly startling view leads us," he says, "to conclude at once that Cleveland will produce ironstone to outlast the supply of fuel by double the time the latter is likely to endure." The answer to Mr. Bewick's fears is that attention has been directed in Yorkshire to the substitution of condensed peat and peat charcoal, in the place of coal and coke, for making iron, and that the best fuel for that purpose actually covers to a vast extent the ironstone, which he fears will outlast the fuel required to smelt it.

Mr. George Murrall, whose long experience as a smelter in Staffordshire and South Wales recommended him for the purpose, was engaged by the Creevelea Iron Company, whose works are near Sligo, to carry out the important experiment of smelting iron ore with charcoal prepared from the condensed peat. This experiment was conducted on a practical scale, and the result was in every way satisfactory, Mr. Murrall observing in his report that he had made about 300,000 tons of good pig-iron, but such iron as he had then made with peat could not be made with coal or coke. He considered it equal to any Russian or Swedish iron.

Digitized by Google

Mr. Anderson, of the Institution of Civil Engineers of Ireland, made an experiment with the iron thus prepared by Mr. Murrall, which showed that the strength of the Creevelea iron was 40 per cent. over that of ordinary Scotch pig. There was, Mr. Anderson remarked, one feature of a very encouraging character. The price of charcoal pig-iron for the making of steel was then 6*l.* 10s., while that of ordinary pig was only 3*l.* 2s. per ton. As the iron produced by peat charcoal was equal to that obtained by the use of wood charcoal, there appeared no reason why Bessemer's process should not be adopted, and the Creevelea iron be converted at once into steel.

The condensed peat was specially tried by the Mersey Steel and Iron Company in a puddling furnace, with very favourable results, the iron so manufactured having being drawn into tubes and T-irons, than which a higher test could not be desired.

There is yet another important purpose for which the condensed peat has proved applicable, and that is, for gas manufacture. It has been found to produce a larger quantity of gas in a shorter time than coal, its illuminating power is nearly double, it is free from sulphur, and leaves in the retort a residue of excellent charcoal, instead of inferior coke. Mr. Jones, the engineer of the Commercial Gas Company, found, in trying air-dried peat for gas purposes, that he obtained extraordinary results, equal, in some instances superior, to those from the best Newcastle coal, but, owing to the presence of a large per centage of carbonic acid, ranging from 25 to 35 per cent., due to the excess of oxygen in peat, and the small commercial value of the coke yielded, he abandoned the hope of substituting it for coal. But upon concluding with Mr. Versmann, consulting chemist to the Commercial Gas Company, a series of experiments with the condensed peat, he was enabled to give as his opinion that it would be found superior to many of the best Newcastle gas coals, and quite equal to several descriptions of cannel coal used in gas manufacture.

Mr. Versmann observes that in estimating the value of a material for gas making, several considerations must be kept in view. The main question is the quantity of purified gas, and its illuminating power. But the yield of bye products is by no means unimportant; therefore, the quantity and quality of coke and fluid products—such as tar and ammoniacal liquor—must be taken into account, likewise the expense of purifying the gas. The practical results of the series of experiments are given by him in the following table:

Digitized by Google

TABLE A.—1 Ton of Condensed Peat yields:

LOCALITY OF PEAT.	Cubic feet of purified gas.	Illuminating power in sperm candles.	Per centage of olefiant gas.	Cwts. of coke.	Gallons of tar and ammoniacal liquor.	Per centage of carbonic acid in raw gas.
Belfast	10.500	15.65	6	8	64	10
Creevelea.........	9.240	18.75	7	8¾	63	9
Welsh	11.000	22.50	8	7	60	10

Table B shows the practical results obtained with a variety of coals, and the comparative value of peat:

TABLE B.—1 Ton of Coal or Peat yields:

COALS.	Cubic feet of gas.	Illuminating power in sperm candles.	Cwts. of coke.	Gas per ton equal to lbs. of sperm.	Sperm, corresponding to gas of Boghead Cannel, No. 2, equal to 100.
Staffordshire	7.100	12.42	13½	302	13.6
Derbyshire	7.600	11.71	17	305	13.7
Himwick	9.300	11.50	14¼	466	16.5
Ravensworth	10.100	13.30	13½	460	20.5
Lochgelly	8.000	18.00	13	494	22.2
Pelton, Newcastle	9.700	15.60	14	519	23.3
Ramsay's, ,, ...	9.700	16.60	13½	552	24.8
Derbyshire Cannel	8.500	20.60	15	600	27.0
Wearmouth	11.900	15.96	13½	651	29.3
Wigan Cannel	10.000	20.00	13¼	686	30.9
Newcastle ,, ...	9.800	25.00	13¼	840	37.8
Wemyss ,, ...	11.600	31.75	14	1262	56.8
Lesmahago ,, ...	10.500	40.00	10	1440	64.8
Boghead ,, No. 1 ...	12.500	40.00	8	1713	77.1
,, ,, ,, 2 ...	13.000	48.00	6	2222	100.
CONDENSED PEAT.					
Belfast	10.500	15.65	8	563	25.3
Creevelea	9.240	18.75	8¾	594	26.7
Welsh	11.000	22.50	7	849	38.2

From these tables the following conclusions are drawn: Condensed peat yields the most favourable results under all circumstances as compared with coal, the gas being superior both in quantity and quality to most coal gases. The yield of coke is smaller, but its value is higher. The purification of peat gas is more expensive than of coal gas, a larger quantity of quicklime being required; but this single objection will be more than counterbalanced by several important advantages, one of which is that peat is worked off much quicker than coal.

There are various other purposes, such as sanitary, agricul-

Digitized by Google

tural, and domestic, for which peat and peat charcoal are adapted, but it is unnecessary now to refer more particularly to them. Works are established at Harwich, near Bolton, and are in active operation, manufacturing under Buckland's patent, the peat being taken from Chat-moss. The samples exhibited were produced at these works.

In concluding the notice of this branch of the subject, it is to be observed that peat has frequently been suggested as a fuel for locomotives, and about twenty years since Lord Willoughby d'Eresby had some peat tried in the Hesperus locomotive, on the Great Western Railway. This engine was of Hawthorne's patent return-tube construction, and required about one-third more peat than coke with equal drafts. Mr. Vignoles has also interested himself in the same direction. There have always existed opposite opinions upon the economical merits of peat; attention is now being actively directed to the useful properties it possesses, but with what results remains to be decided. It is, however, to be hoped that the hitherto obnoxious bog may be converted into a source of national and individual wealth, affording employment for labourers and artificers at home and abroad, and yielding an efficient substitute for coal in all its varied uses.

We have now arrived at the fourth and last division of the subject—manufactured or artificial fuel.

The considerations advanced in the early part of this paper, combined, doubtless, with a spirit of enterprise and commercial speculation, have led to various combinations of combustible substances, with the view of producing a useful and economical fuel, and at the same time utilising comparatively worthless materials. It would be useless to enumerate the many attempts that have been made to manufacture an artificial fuel which would fulfil the necessary requirements of a good and serviceable fuel, or the numerous amalgamations that have been proposed from time to time. Very few have proved commercially successful, or even practically adaptable to the necessities of steam engineering. Of the few that have succeeded, three only appear to have attracted particular attention by their merits. These are respectively Warlich's, Wylam's, and Bell's patent fuels, and they occupy very good positions in the tables of results of Sir H. de la Beche and Dr. Lyon Playfair's experiments previously noticed. With regard to their commercial position, Warlich's would seem to have maintained the supremacy; information respecting the other two is scant and questionable.

Warlich's patent fuel is manufactured of the best Welsh steam-coal screenings, deprived of foreign matter by machinery, and then incorporated with a bituminous substance. The mixture is passed through pug-mills, and pressed into square blocks

Digitized by Google

$9in. \times 6in. \times 5in.$, under a pressure of three tons per square inch, and are afterwards subjected to about 800 deg. of heat in retorts, by which means the noxious gases always existing in coal are neutralised and driven off, and the fuel rendered not only impervious to the influence of climate, but also perfectly free from all liability to spontaneous combustion.

Among the advantages possessed by this fuel may be noticed its freedom from small or dust. Being in square blocks it is well adapted for stowage, and, forming a compact mass, is free from the evil present in the finest Welsh coal—a large percentage of dust; in fact, all the fuel shipped is available for use at the port of discharge. Economy in space is another point. It occupies about one-third less space than ordinary coal, and from its compact and uniform character it can be stowed on deck and in other places quite unfit for the stowage of coal. Economy in consumption—a most important feature—is abundantly proved by the Government trials made at Portsmouth, and presented to the House of Commons in June, 1858.

All coal deteriorates rapidly if exposed to the weather, and in course of time becomes comparatively useless; but from its peculiar manufacture, this fuel suffers no deterioration from the injurious effects of climate. Its freedom from spontaneous combustion is consequent upon the adaptation of heat in its manufacture; there has not been an instance of spontaneous combustion during the twenty years this fuel has been in use. It effects a great saving of fire-bars. Welsh coal, as is well known, is very destructive in this particular. In some experiments conducted by Dr. Lyon Playfair, at the instance of the Government, with a view of ascertaining whether the health of passengers and crews were at all imperilled by the storing of fuel on board ship, several interesting facts were eliminated. The fuel was put to severe tests and was found unobjectionable. On coking some of the fuel it produced 83.47 per cent. of coke, thus showing that it contained a larger amount of fixed carbon and less volatile matter than ordinary coal. The amount of ash was 5.67 per cent.

This fuel is very largely used on foreign railways, both on the Continent and farther abroad, there being depôts in several parts of the world. Works for its production exist on an extensive scale at Swansea, where 100,000 tons are produced annually, the working time being ten hours per day; by night and day work the annual yield of these works could be doubled without increasing the present staff. The usual stock is from 15,000 to 20,000 tons; a thousand tons can be loaded in ten hours, so great are the facilities the size and form of the fuel could afford in this respect. Its cost is about 12s. per ton delivered at the works, which is also the price plus freight to any other part.

Digitized by Google

It is observed, in conclusion, that the object of the paper is not so much to throw a new light upon the present position of the question whereof it treats, as to adduce facts, opinions, and evidence which may awaken research or promote discussion with a view to ultimate practical improvement. Should this result obtain in ever so remote a degree the purpose of the paper will not have been unanswered.

February 1*st*, 1864.

G. W. ALLAN IN THE CHAIR.

ON FUEL.

BY PERRY F. NURSEY.

DISCUSSION.

Mr. OLRICK opened the discussion by drawing attention to that portion of Mr. Nursey's paper which referred to the relative value of fuel and the actual result got out of it. It was well known that only a very small portion was obtained of that which, according to theory, ought to be. There had always been a great difference between theory and practice, but he would confine his remarks to what could be got practically. In the "Black country" the steam boilers were entirely exposed to the weather, which by itself condensed a great deal of steam, and steam was fuel. He maintained that every chimney that smoked was so much fuel wasted, and consequently, when the country was black with smoke, there was a large amount of waste. It might also be observed that the safety-valves blew constantly out a large quantity of steam, which was also a waste of fuel. Although they were not discussing the question of boiler construction, yet he might be allowed to refer to some points wherein the country was concerned. He alluded to the British Navy. Taking all the boilers in the Navy, there was not one of them that did not consume nearly double the quantity of fuel they ought to consume. He did not believe there was a steamer in the Navy that did not smoke. He thought it was right to impress upon the engineering profession to take a little more trouble about the construction of boilers. In all manufacturing districts, and particularly where coal-mines were in the neighbourhood, they did not care what amount they used. Referring to some remarks Mr. Nursey had

Digitized by Google

made in his paper, he would state that, although peat gave out heat much quicker than coals, the latter would last much longer. Peat could no doubt be used with great advantage where steam was required to be got up quickly.

Mr. COLBURN said that in Mr. Nursey's very comprehensive paper nothing had been said either of wood or of petroleum as a fuel. As far as wood was concerned, it was a very important fuel in America, and he believed upon the Continent, and in India, and in many of the countries in South America. He did not know, however, that there was much to be said about burning it; 1 lb. of it would evaporate from 2 lb. to 3 lb. of water. As far as petroleum was concerned, that possessed heating power equal to twice its weight of coal. The question was, how cheaply it could be brought to this country.

Mr. LATHAM said the subject of fuel was one of great importance, and one in which this country was particularly concerned, as, owing to the vast and favourable arrangement of our coal measures, our manufactories were kept in motion at a comparatively low cost; consequently we, as a nation, were enabled to compete favourably with those not so fortunately circumstanced with regard to their supplies of fuel. Attention had been drawn to the results likely to occur upon the exhaustion of our coal measures, and although the day when such a calamity would occur was far distant, yet the fact of the possibility of their being exhausted taught us that we had no room for prodigality and waste, but that we should husband and economise our resources to the utmost. To attain that end and produce an economy in the consumption of fuel, we must turn our attention still closer to the attainment of perfect combustion in our furnaces, and to the ways and means of extracting and utilising the largest amount of heat during the process of combustion. In testing different fuels in the same furnace and under the same circumstances, he had often found a very great difference of results, but by taking the worst description of fuel tested, and adapting the furnace for its consumption, very good results immediately followed. Peat as an article of fuel had been brought prominently forward in the paper, and if the results arrived at were correct, it would, at some day not far distant, become an important article, especially in those cases where an absence of the sulphurous vapours, given off during the process of combustion of nearly all coals, was an absolute necessity.

Mr. MORRIS wished to know whether Mr. Nursey had seen the experiments on peat himself, or, if not practically acquainted with the facts, whether he was personally acquainted with the gentlemen on whose authority they were given. He quite agreed with Mr. Olrick as to the enormous waste of coal in the colliery dis-

Digitized by Google

tricts, which resulted from leaving the tops of the boilers and the steam-pipes uncovered and exposed to the weather. Not only was there a waste of fuel, but a waste of boiler power, and additional boilers were required to replace the steam lost by condensation.

Mr. A. WARREN said that in India wood was a very important fuel, as coal could not be obtained at any reasonable cost. It burnt very well, and those who used it did not at all wish to have coal. All that was required was a sufficiently large fire-box, and the steam could be got up a great deal faster than by coal. Upon the Indus they had no difficulty in keeping up any amount of steam they required. They tried some coal from Australia—not so good, certainly, as English coal, but not very bad—and it would not compete with wood at all. Two and a half tons of wood would go about as far as one ton of coal.

Mr. COLBURN mentioned that the size of the fire-boxes in American engines was generally smaller than in English locomotives. Boilers burning wood as a fuel lasted much longer than with coke, but some care was required in the use of wood.

Mr. HOUGHTON had made a few experiments with peat as a fuel for boilers, but he was sorry to say the result had not come up to his expectations. It was true the experiments were not made upon an extensive scale, but upon a comparatively small one. Ten or twelve tons were tried to be burnt in the furnace, but the furnace could hardly be supplied quick enough with peat to keep up steam. He thought, however, that it might arise from the quality of the peat, which was obtained near London, and questioned if it was so good in quality as that obtained in some parts of Ireland. As there were 140,000 acres of peat in the neighbourhood of London, averaging from 5 to 15 ft. in depth, any one who discovered the means of economically treating it as a fuel would become a great benefactor to the community at large.

Mr. OLRICK said that, during the time he was a sea-going engineer, he had many opportunities of comparing the quality of coals that had been kept in government stores for some time with those obtained direct from the collieries, the latter being in every respect far superior. He had also had opportunities of trying Warlich's patent fuel, which, with good draft, could be well used by itself, and when it was mixed with coal very good results were obtained.

Mr. MORRIS, in reply to Mr. Colburn's inquiry as to the merits of Welsh and Newcastle coal, gave his experience at the Kent Waterworks, where Welsh coal had been used for many years in order to avoid smoke, nevertheless they were fined for making smoke; after this, mixtures of coke and Welsh coal and coke

Digitized by Google

and Newcastle small coal were tried, but at length screenings of house coal were successfully used, from 1 to 2 cwt. being thrown in a heap on one side of the fire, which soon caked on the top and compelled all the gas to escape downwards, where, coming in contact with the hot coke, and the air entering through the fire-bars, perfect combustion took place till the heap was reduced to a mass of coke. The result had been an immense saving, the price of Welsh coal being about 25s. per ton as compared with 10s. for the screenings. The effective duty obtained from the pumping-engines when burning Welsh coal averaged 85 million, and when screenings of North Country coal, 70 million foot-pounds.

Mr. BARTHOLOMEW thought the general opinion seemed to be that wood would not burn advantageously in furnaces constructed for coals. No doubt it would not, neither did he think it was fair to expect it should. If furnaces were constructed to meet the peculiarities of wood, as satisfactory results in the way of evaporation would be obtained as from coal; but, independently of that, the fact that there were certain products of combustion in coal which had a deteriorating effect upon the metal of which fire-boxes were constructed, and which products wood did not contain, was an argument in favour of the latter. If the wood were compressed, and the whole of the moisture removed, he thought there would be a fair comparison between the merit of wood and coal, and it might then be compared weight for weight.

Mr. COLBURN said that some instances of difficulty in burning small coal were attributable to the short distance between the bars and the crown—there was no room for combustion. If 30 in. were allowed, much less difficulty would be experienced.

Mr. OLRICK mentioned that he once tried one of Maudslay's boilers, which did not give good results because the boiler was rather too small for the engine, but by a judicious alteration, whereby a sufficient amount of air was admitted at the fire-doors, the same boiler gave much better results, saving about 2 cwt. of coal per hour, and ceasing entirely to smoke.

Mr. NURSEY, in reply, expressed regret that there had not been a fuller discussion upon the subject of the paper, which was purposely made very general that a wide margin might be left for detail information, which he hoped to have elicited.

Since writing the paper, he had been informed that a patent had been taken out by a Mr. Sterling nearly twenty years since, under which, for a short time, a useful fuel was manufactured which was composed of slack-tar and clay thoroughly incorporated. Sterling's patent fuel, however, was not a commercial success for want of capital.

Digitized by Google

The results given by Mr. Olrick of his calculations of the difference between the theoretical and practical value of coal, which as he, Mr. Olrick, stated, were at variance with those in the tables by Sir H. De la Beche and Dr. Lyon Playfair as given in the paper, only went to prove the variableness of theoretical result on that point, and the necessity for more clearly-defined laws relating to the properties and powers of fuel. As regarded the comparative durability of condensed peat and coal under combustion, it appeared from various trials that there was little or no difference between them in that respect. Mr. Colburn had adverted to petroleum as a fuel. He (Mr. Nursey) believed the cost was about 12*l.* per ton. He was informed that the petroleum wells had stopped their supply and the company had been dissolved, but he was also aware that private experiments on an extensive scale were being conducted with the view of determining the best method of practically applying petroleum as a fuel for steam-boilers. Mr. Latham had inquired the comparative cost of peat and coal. The condensed peat was produced, and could be sold at about the same price as coal at the pit's mouth. There could be no question that peat possessed many advantages over coal as a steam fuel. The absence of sulphureous vapours, and other deleterious products of combustion, contributed much to the preservation of fire-boxes.

With regard to Mr. Morris's observation, he (Mr. Nursey) had not witnessed the trials and experiments of the condensed peat, but they were well authenticated, and their results placed on record, and he had given the authority in each case. Mr. Houghton had mentioned that he had made some experiments with 10 or 12 tons of peat, which, upon being burned in a furnace, gave very bad results. That was easily accounted for, as the peat was simply dried peat, which would contain a large proportion of coarse fibre, and would make an inferior fuel; but the condensed peat manufactured under Buckland's patent was a far more perfect fuel, as the coarse roots were removed, the smaller fibres broken up, and all the moisture expressed; hence the good results obtained in all cases where condensed peat was used. In using the condensed peat the only alteration necessary in the furnace was to place the fire-bars a little closer together than was usual when coal was used, but the extraordinary results stated in the paper had in all cases been obtained with furnaces of the ordinary construction.

The cost of machinery for the manufacture of condensed peat and peat charcoal had been adverted to. Under Buckland's patent that item was very moderate. A peat-mill to make about 6 tons of peat per day cost about 55*l.* The ground peat was

Digitized by Google

delivered into a brick moulding-machine, costing 40*l.* The moulded peat could be air-dried under a sufficient cover to protect it from the sun. A 6-horse power portable engine was required, the cost of which would be 200*l.* Thus the total cost of machinery for producing peat for fuel was, say, 300*l.* The additional expense of buildings would be governed by local circumstances; simple shedding would answer most purposes. To convert the peat thus produced into charcoal required a further outlay of about 150*l.* for ovens fixed complete. The actual cost of producing peat fuel at works in operation in England was 5s. per ton, and of peat charcoal 10s. per ton; those were full prices, and included all labour cost, &c. The cost of taking peat from the bog and delivering it into the machine varied from 1d. to 4d. per ton, but, as a rule, it might be taken at 2d. per ton. In converting the peat into charcoal a good grease was obtained, which was sold for about 15s. per cwt.

The object of the paper was to promote discussion and to elicit information upon a very important matter, and that it had succeeded but partially in so doing, perhaps went far to prove the necessity for further inquiry into the nature and properties of fuel.

Digitized by Google

F COKE OVENS.

ig. 1

ction *Plan*

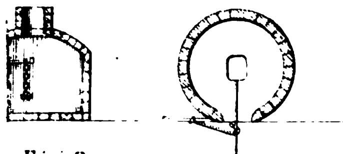
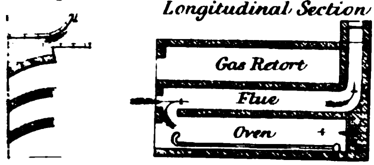


Fig. 2

Longitudinal Section



nge

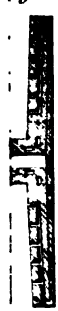


Fig. 6

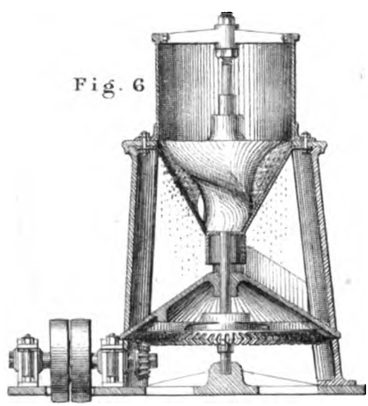


Fig. 4

Section at Chimney

Fig. 5

Elevation

p Bucklersbury, London

Digitized by Google

Digitized by Google

February 15th, 1864.

H. P. STEPHENSON IN THE CHAIR.

ON THE MANUFACTURE OF COAL GAS.

By A. F. WILSON.

ATTEMPTS have been often made to manufacture gas from other substances besides coal—oil, resin, peat, and even water having in their turn commanded capital for a fair trial of their merits. Of all these, however, coal has alone stood the test of commercial success, those companies formed for other schemes having either been dissolved or become converts to its superior advantages.

Common bituminous coal obtained from the mines of Northumberland, Durham, York, South Wales, and a few other coal districts, is the kind from which most of the gas of this country is manufactured; but a gas of much richer quality is also made from cannel, or Scotch parrot coals, which, though more expensive in production, has the advantage of superior illuminating power, and on this account has been lately extensively introduced into London, several companies now supplying it through independent mains at an increased charge to the consumers.

Cannel gas is also largely manufactured in Scotland, where the proximity of the parrot coal-pits greatly assist in cheapening production, thus allowing gas companies to retail it at a comparatively low charge, and with its manifest advantages over every other artificial light, causing its almost universal introduction wherever gas companies have mains for its supply.

Coals from the following mines are now generally employed by gas companies in the metropolis and surrounding district:—Pelaw, Leverson's Wallsend, Pelton, New Pelton, Deane's Primrose, Garesfield, South Peareth, Urpeth, Washington, Yorkshire Silkstone, Haswell, West Wear, Wearmouth, Brancepeth, South Brancepeth, and Ravensworth Pelaw.

The resulting products of carbonisation of these coals, when an exhauster is employed, will be found to give about the following average per ton:

Digitized by Google

Gas	9500 cubic feet.
Coke	13 cwt., or one chaldron.
Tar	10 gallons.
Ammoniacal Liquor . . .	13 gallons.

In these the quantity and quality of gas and residue of coke do not vary to any very extensive degree, but with cannel and Scotch parrot discrimination becomes much more difficult, as the quantity and quality not only differ considerably with different coals, but while some produce a fair, useful coke, in others, such as Boghead or Torbanehill, the residue after carbonisation is little else than silicate of alumina, or common clay.

Ammonia, a compound of nitrogen and hydrogen, is converted into sulphate of ammonia, sal ammoniac, carbonate of ammonia, &c. &c.

Tar, which is a hydrocarbon, after producing naphtha and light oils, becomes useful as asphalt, or for exterior paint-work. Benzole, the base of our newly-discovered dyes, is extracted from the naphtha, which, besides, is either used as a solvent for india-rubber and gutta-percha, or yields a brilliant light when burned in a common lamp.

The residual coke in the retorts is chiefly composed of carbon, invariably accompanied, however, by a quantity of ash, which, besides its earthy base of silicate, usually contains sulphur and other deleterious substances.

The coke is principally used for common furnace work. It is neither hard enough nor sufficiently clean for the ironfounder's cupola, and no profitable method has yet been discovered of purifying it so as to make it useful as pure carbon.

Coal gas as it issues from the retort is chiefly composed of light carburetted and bi-carburetted hydrogen or olefiant gas, accompanied by condensable vapours and other gaseous impurities. The condensable vapours are principally hydro-carbon compounds, which become deposited in the form of tar oil, and amongst a variety of deleterious substances may be mentioned, as the chief, ammonia, carbonic acid, carbonic oxide, and sulphuretted hydrogen, but the value of coal gas principally depends on the presence of bi-carburetted hydrogen, and the greater the proportion of this the higher will be its light-giving properties.

With these preliminary remarks we will now proceed to notice *in extenso* some of the chief departments of the manufacture, afterwards noting a few of the most important details of the construction of the apparatus.

The Retort-House

Should be a building sufficiently large to allow for plenty of room in front of the retorts for a storage of coals and good space

Digitized by Google

for drawing the retorts, and at all times so placed and planned that an easy extension of the house may be made if required.

A space of at least 20 ft. in front of the retorts, a height of at least 16 ft. to 20 ft. to the springing of the roof from the ground line, and a good ventilation in the roof for allowing the smoke, &c., to escape, are the principal points to be observed in designing a retort-house.

The floor of the retort-house is usually paved with stone, except for 6 ft. immediately in front of the retorts, where it is desirable to pave it with fire-bricks, for if stone was used the heat from the fire and the hot coke from the retorts falling upon it would soon destroy it.

Good-sized doorways should be provided for the easy removal of the hot coke from the retort-house.

Retorts.—(Plate No. 1.)

The bench of retorts in large gas-works is usually placed in the middle of the house. The retorts are built in ovens or settings, and are now generally preferred open through and through with mouthpieces at both ends. The first process connected with the manufacture is the heating up of the retorts, which is done by furnaces, one at each front of the bench, and these are charged, and the heat kept up with the residual coke after the coals have been carbonised.

Sometimes, but principally in cannel gas-works, a quantity of tar is introduced above the furnace to assist the coke; and another way of applying this substance is by running a slender stream in the centre of the bench, with the view of more thoroughly equalising the heat. But if used in this way an air flue must be carried in the brickwork forward to the place of combustion, as otherwise full benefit is not derived from the tar, and the place quickly becomes choked with unconsumed pitch. Tar is, however, generally found superfluous for ordinary heats, and is only used when it is necessary or customary to charge the retorts oftener than every six hours.

The flame and hot draft of the furnaces are made to circulate thoroughly throughout the setting, traversing as great a space as possible round, under, and above the retorts before egress is allowed to the main flue communicating with the chimney. Evaporating chambers, where the wet lime, when foul, is run from the purifiers, are usually built in connexion with the main flue, and the spare heat in this way is made to do duty in reducing the lime to a pulpy mass, to be afterwards used for luting the retort lids, under the cognomen, among the workmen, of "Blue Billy."

The retorts, being heated sufficiently, are charged at each end

Digitized by Google

with a scoopful of bituminous coal, after which the lids are screwed up, and the process of gas distillation commences.

Light carburetted hydrogen, free hydrogen, ammonia, and other light gases, are rapidly evolved during the first hour of the charge; and, following these, olefiant gas, mixed with some of the heavier impurities, gradually begin to rise towards the latter hours of the distillation. Carbonic acid, sulphur, and other heavy vapours, are freely given off, so that it is at all times a false economy to protract the duration of the charge beyond an ordinary period; the additional cost of purifying material and extra labour, besides depreciation in the quality of gas, more than counterbalancing any extra quantity that may be obtained.

To limit or define the time for distillation of the various gases is, however, practically impossible, and there is no doubt that, to a certain extent, portions, more or less, of each of them pass off from the beginning to the end of the charge.

Seven retorts in a bed is the number now allowed to combine most profitably the saving of fuel with the quantity of gas manufactured when using common bituminous coal. In cannel works three to five is the maximum, but in these much higher heats are required, and, the retorts being charged oftener, the heats are more difficult to keep up.

Fire-clay *versus* iron was long a standing cause of dispute among gas-engineers, but fire-clay has gradually gained the ascendancy, and fire-clay retorts are now almost universally adopted.

Round, flat D, and oval are the shapes employed, and each of these has its advocates and opponents, who argue for or against its several points of economy and adaptability.

Flat D retorts are certainly allowed to have a more extensive and equal heating surface than either of the others, and on that account are supposed to produce a larger quantity of gas per ton of coals carbonised; but, on the other hand, they are seldom found to expand and contract equally, and, however carefully protected, the corner next the furnace invariably succumbs to the fire.

Round retorts contract and expand equally, and are always found to last longest, but if made of a large size do not give satisfaction in their carbonising properties. They are generally, for convenience, set with others of the oval shape, and these having the advantage, from their form, of a larger heating surface, combined with the strength of an arch, and regularity in expansion and contraction, manufacture more gas per ton than the round, and are nearly as durable, and thus, one is led to think, ought to produce more profitable results.

Clay retorts, when first heated, have a tendency to crack, and

Digitized by Google

split up in various places, caused partly by expansion, but also, in a great measure, by the expulsion of vapour from the clay. The result of expansion cannot be avoided, but the effects sometimes produced by the expulsion of moisture may be almost entirely prevented by a slow and careful process of heating, in which case the retorts will gradually acquire their intended colour without perceptible damage. Similar caution ought also to be exercised in cooling down when the oven is no longer required for the season; contraction, if allowed to take place too suddenly, being most destructive in its effects, and great care should therefore be taken by closing up every aperture by which air can gain admittance, after the fires have been withdrawn, to sustain as long as possible the dead heat that is inside the bench.

A carbonaceous crust, a deposit from the gas, that adheres firmly inside the retorts, is the cause of frequent annoyance in all gas manufactories.

This is formed by a decomposition of a portion of the carburetted hydrogen in its passage along the heated sides of the retorts to the ascension pipes, and the formation is also greatly assisted by the pressure generally existing inside the retorts, and which cannot be obviated except by an exhauster working at a vacuum stronger than the seal of the dip-pipes. The formation of carbon is beneficial so far as it conduces to fill up any cracks that may have been caused by heating up; but when it accumulates to such an extent as to obviously reduce the heating surface, it becomes necessary to resort to some means for its removal.

Scurfing or burning out is the process adopted, the lids being removed, and the atmosphere allowed to circulate freely in the retort, thus causing the carbon gradually to consume until, being slightly detached, a hold is gained for the scurfing-irons, by which it is ultimately, though often with great difficulty, removed. A blast or fan is sometimes employed, by means of which a current of air can be directed against any part considered most vulnerable, or of greatest advantage for action with the scurfers; and in this way the carbon is removed in a much shorter time than when left to the ordinary contact of the atmosphere.

Another frequent source of annoyance is the choking or stoppage of ascension pipes. The causes are generally to be found either in the pipes being too small, the irregular or improper charging of the retort, or the formation of the kiln allowing the heat to circulate too freely in the front. The main flue should be large and easily got at. The chimney should be in such a position as to draw equally from both ends of the bench.

Digitized by Google

Hydraulic Main, Ascension Pipes, &c.—(Plate No. 1.)

Pipes connected with the mouthpieces, called the ascension pipes, conduct the gas to the hydraulic main. This is a large pipe, partly filled with water when the works are started, into which the ends of the pipes from the retorts are made to dip, and by this means form a seal by which the gas is prevented from finding its way back, either to those retorts that the workmen may be re-charging, or to other parts of the bench that for the time may be out of action. Wrought-iron in preference to cast is now generally adopted in the manufacture of new hydraulic mains, its lightness, strength, and elasticity enabling it to withstand better the alternate and unequal heating and cooling of the bench, this strain affecting, by expansion and contraction, not only the main and its supports, but also the large extent of pipeage to which they are connected.

The size of the main and depth of hydraulic seal are both directly dependent on, and ought invariably to be determined by, the following absolute principles, viz.:

1st. The number and area of dip-pipes.

2nd. The greatest amount of back pressure that can at any time be thrown upon it when the apparatus is in full work, should the exhauster be suddenly brought to a stand, or require to be dispensed with.

3rd. The largest quantity of gas intended to be passed from it per hour.

When the main is hung in front of the bench it is found that, unless sufficiently far removed, the flame caused by drawing the charge acts strongly upon it, heating it to a much greater degree than when supported at the back of the ascension pipes. This heat, in either case, has the effect of boiling the tarry fluids inside to a pitchy mass, and in cannel gas-works, especially when a large quantity of tar comes over with the gas, causes sometimes a very considerable amount of annoyance.

The obvious remedy is to remove the main further from the strong heat of the bench; but where it is found difficult, or deemed inadvisable, a very ingenious contrivance is sometimes resorted to. This plan is to withdraw the tar as completely as possible from the hydraulic, leaving in its place the ammonia liquor, which is here plentifully deposited, and on which the heat has no other effect than to cause evaporation. A simple method of doing this is, instead of allowing tar and water to overflow promiscuously along with the gas, as is usually the case, to attach a pipe to the bottom of the hydraulic, and carry it up with a bend outside to the level of the fluid that is inside the main—when the tar, being of a heavier specific gravity than the water,

escapes from the bottom, overflows the pipe, and leaves the seal inside still at the correct level. It is obvious, however, that, by leaving this pipe open at the overflow, awkward consequences might occasionally ensue, and accordingly it becomes necessary in this arrangement to make a counter-connexion from the top of the main, which, allowing a free circulation of gas in the pipe, prevents any danger of it at any time acting as a syphon, as otherwise it might occasionally be liable to do.

Tar Well and Condensers.—(Plate No. 2.)

The condensation of tar and ammoniacal liquor, which commences immediately after the gas leaves the retorts, makes it necessary to provide some place of deposit where the overflow of the hydraulic and other places may be stored. The tar-well is usually a brick or cast-iron tank, into which a branch pipe from the main is inserted and sealed in a stationary lute at the bottom. Still further to separate all condensable vapours before allowing the gas to pass to the purifiers, a set of condensers or coolers is provided, through which the gas is made to circulate until it is reduced to a temperature bearing some approximation to the surrounding atmosphere.

These are, in most cases, formed by rows of upright pipes resting in a chest at the bottom, which acts as a receiver for condensed matter. Sometimes the pipes are made concentric, the gas having a passage betwixt the rings, and the centre is either open to the atmosphere or supplied by a constant run of cold water. Another very effective condenser is simply an oblong narrow chest, the width being no greater than the main pipe by which it is supplied. It is usually set up on its narrow base, and the inside is divided by partitions of wood in such a way as to make the gas traverse several times through the entire height before making its exit at the opposite end from which it had entered.

The face plates are also thickly studded with sockets, through which 2-in. pipes are passed and tightly jointed at both sides, and these, breaking and retarding the gas in its passage, and being kept cold with the draft of cold air continually passing through them, expose the gas in a comparatively limited space to an immense area of condensing surface.

A formula of 10 square feet of surface for every 1000 cubic feet manufactured in twenty-four hours is generally recognised as a fair approximation to the condensation necessary; but this rule in general is not strictly attended to, as it is well known that cannel requires a greater extent of condensing area than common gas; and, besides the difference of an exposed from that of a

Digitized by Google

sheltered situation, the nature of the climate must also exercise an important influence in the calculations of a proposed condenser. Without attaching too much importance to this part of the apparatus, it is still essential that some approach to a definite proportion should prevail, as, on the one hand, condensers ignorantly erected, of extravagant proportions, add considerably and unnecessarily to the cost of the works; while, on the other, insufficient condensing surface is the cause of continual waste, as the valuable tar oils are thereby carried forward either to the washers or purifying vessels in the one case, being sold at a cheap rate as ammoniacal liquor, and, where washers are not employed, causing in the purifiers a needless waste of purifying material.

Exhausters.—(Plate No. 3.)

Although not invariably adopted, it is now generally considered preferable to condense the gas before using the exhauster, the advantages of which are now so universally admitted.

Without discussing these advantages at any length, it is, nevertheless, impossible altogether to avoid mentioning a few of them, as there are still gas-engineers to be found who, with plenty of work for an exhauster, entirely ignore this valuable adjunct, and, for a paltry consideration of the slight expense incurred to begin with, neglect a positive saving of hundreds of pounds annually.

By the use of the exhauster a large per-centage of gas, which formerly escaped by the chimney, is saved and made profitable. Two-thirds of the carbon which was formerly left in the retorts is now preserved in its original form, and adds to the quality of the gas. Retorts do more work in the same time, and last much longer, and purifying vessels can be used, which without it would never be attempted.

The exhauster was invented, as the name implies, to suck or exhaust the gas from the retorts, and afterwards force it through the vessels used for purification; and, in whatever form they may be, the principle is that of a rotary or direct action pump. Beale's and Jones's are both rotary, Anderson's has a direct action; and, besides these, there are others occasionally to be found, which, however, it is unnecessary here to particularise.

Beale's exhauster was brought out originally as a rotary steam-engine, although, in that capacity, it has never been very extensively employed. One of the metropolitan gas companies, however, now, or lately, used an engine of this kind for driving their machinery, and another, of very slightly different construction, as a gas exhauster. Mr. Beale states that the apparently toy-like engine that drives his extensive machinery at Greenwich has been tried with a beam-engine of the most improved construc-

Digitized by Google

tion, and found to do the work quite as satisfactorily, with much less expenditure of fuel.

The outer case is a cylinder carefully bored out, having ends planed and closely fitted, and each of these ends carry bearings for a cast-iron shaft, about one-third out of the centre. This shaft carries along with it, cast in the same mould, a cylindrical case, transversely through the centre of which is an oblong slot faced in the edges, through which the slides of the exhauster work.

There are two of these slides to each exhauster, carefully planed and fitted all round, placed in the slots opposite to each other, and supported outside with projecting studs carried in segmentary circular slides, and revolving in grooves in the outer periphery of the ends.

The shaft being fixed considerably under the centre, the inner cylinder revolves close upon the bottom of the case; and, consequently, leaves a clear space above, which is filled by the slides, as they alternately advance and recede, revolving in the outer groove, and sliding in the fitted slot of the inner cylinder.

The gun-metal friction rollers, with which these exhausters are usually fitted up, speedily succumb to the action of the unpurified gas; and some other metal that would better withstand the acids and alkali, so prevalent at this stage of the manufacture, would be a decided improvement.

Jones's exhauster is a similar rotary pump, formed by the action of two blades, shaped like an open figure eight, working in a closely-fitting oval case, and carefully planed at the ends. These blades bosom into, and work off, each other by spur wheels; and their revolutions, being counter to each other, have the effect of sucking and expelling the gas.

Anderson's exhauster is simply a double-action pump, with the strokes differently arranged. Objections are sometimes raised to it, on account of a supposed unsteady action, but this unsteadiness is usually traceable to some of the gearing being slightly out of repair.

Gas governors (Plate No. 3) are now in very general use for regulating the throttle-valve of the steam-engine, instead of the ordinary governor balls. The governor is attached to the inlet of the exhauster, and is made on the principle of pressure or suction, elevating or depressing a light cylinder, working in a water lute of sufficient depth.

If the exhauster is worked at a slight pressure, the cylinder may be made sufficiently light to be self-acting; but if an exhaust is maintained on the water-gauge, counterbalance weights, equal to the exhaust on the area of the cylinder, must be applied; and the oscillations, as the suction increases or diminishes, will regulate to a nicety the speed of the engine.

Digitized by Google

As various contingencies often arise, which necessitate the stoppage or changing of exhausters, it is necessary also to provide a self-acting apparatus of some kind, whereby a means of exit may at all times be secured to the gas, should the exhauster be suddenly brought to a stand; and, at the same time, constructed in such a way as to thoroughly prevent further passage when it again resumes work.

For this purpose a by-pass valve (Plate No. 3) is attached between the inlet and outlet gas-pipes. It is, in most instances where an exhaust is employed, simply an ordinary flap, fixed in such a way as to be kept completely gas-tight, by the pressure in front and exhaust at the back. But when the exhaust is withdrawn, and the pressure equalised at both sides, it hangs loose, and allows the gas to pass independently of the exhauster.

Another form of by-pass, often used when it is not customary to work at an exhaust, is a common lute-valve, counterweighted, so as to rise should the pressure at the back at any time be equal to a fixed maximum height of the water-gauge.

Engines.

Various kinds of engines are used; among others, horizontal, beam, and table-engines.

In works of any importance duplicate engines and boilers are absolutely essential; and a spare exhauster is also advisable, as a safeguard against accidents that occasionally occur in the depth of winter, when the want of an exhauster might lead to serious confusion.

Purification (Plates Nos. 4 and 5).

The average proportion of impurities requiring to be removed in gas made from Newcastle common coal consists of about 1½ parts ammonia, 8 parts of sulphuretted hydrogen, and 25 parts of carbonic acid, in 1000 of gas. A variety of other substances —generally different combinations of the same bodies—are also present; and one of these, the sulphuret or bi-sulphide of carbon, has hitherto defied all practical attempts made for its removal.

The Rev. Alfred Bowditch recently patented a method of removing this offensive impurity, by passing the gas through an ordinary purifier filled with heated lime and clay; but although successful to a fair extent, when tried on a small scale, its efficiency in large works is very dubious, and has never yet been satisfactorily proved. Mr. John Leigh, in a report to the Manchester Gas Company, lately published, states the quantity contained in 100 cubic feet of gas at from 13 to 109.8 grains—a considerable variation, no doubt, but one which can be easily

Digitized by Google

accounted for when we consider the gas as made from very different qualities of coal. Further on Mr. Leigh describes a process of obtaining sulphide of ammonium from gas liquor, which, when brought in contact with the gas, was found to combine and remove from it the greater portion of the sulphuret.

Ammonia is the first in the order of impurities which requires attention for removal, and this is usually accomplished by employing water as an absorbent.

Ammonia as it issues from the retort combines with, and is partly neutralised by, the carbonic acid and sulphuretted hydrogen which accompanies it; and being saturated by the watery vapour of the coal, becomes condensed in what is known as ammoniacal or gas liquor; but as, after passing the condenser, a quantity of the ammonia still remains with the gas, other means of removing it must be adopted.

The vessels originally used for this purpose were called "washers," the arrangement being to surge the gas through a series of water lutes, and so saturate or absorb the ammonia. When washing in this way, however, a quantity of the oily hydro-carbons are also absorbed, and the additional pressure thrown necessitates an increased power of exhauster.

The Scrubber (Plate No. 5).

A vessel filled with coke, bricks, furze, or some other body of a similar nature—was first used simply as an auxiliary to the condenser, for the purpose of removing any tarry substance that might be carried past the condensers by the mechanical impetus of the gas; but latterly it has become customary also to inject water by a rose pipe at the top of the vessel, and thus, by keeping up a constant humid spray, the scrubber not only fulfils its original duties, but also becomes a powerful absorbent of ammonia, without increasing, beyond a very slight extent, the pressure thrown by the other purifiers. The water in its downward progress washes the ammonia from the coke, or whatever obstructive agent may be employed, and being collected in a cistern at the bottom is repumped until a sufficient strength has been attained, when a fresh supply of water becomes necessary.

At the Bankside station of the Phœnix Gas Company both washers and scrubbers are employed. The washers are oblong in shape, 30ft. long, 6ft. 6in. wide, divided into five shelves. Each shelf, when filled to the water level, contains about 250 gallons. The water dip is 1½in. to 2in., and the gas is forced through directly from the exhausters; afterwards passing to the scrubbers.

Digitized by Google

The scrubbers—two in number—are round vessels, 10ft. diameter × 19ft. 6in. high, filled with perforated glazed bricks and furze, water being continually pumped and repumped through them both. With this arrangement it is found that, when using 100 tons of coals per day, five shelves of the washers, of an average of 7oz. liquor, can be shifted weekly, or at the rate of 1.8 gallons per ton of coals. Whereas with the scrubbers, although the gas has previously passed the washers, 450 gallons of liquor, of an average strength of 8oz., is produced daily, or at the rate of 4.5 gallons per ton; thus proving that scrubbers are much more effective than washers for absorbing ammonia.

Acids of various kinds are also employed as absorbents of this alkali, but a question has been raised whether these do not also destroy part of the olefiant properties of the gas. That this, in theory, ought to be the result cannot properly be denied, and yet the adoption of the process in some of the largest gas-works in the kingdom would seem to imply either that in this case practice is opposed to known theory, or the cheapness of the process, or commercial value of the product, compensates for any loss in quality of gas that may thereby be sustained.

For the removal of sulphurettod hydrogen and carbonic acid the most effective agent, and, until the last few years, the only substance employed since the original introduction of it by Winsor, is the ordinary hydrate of lime. Unfortunately, however, in removing the lime from the purifiers, and afterwards storing it in an open heap exposed to the atmosphere, a chemical action ensues, which creates a decidedly unpleasant effluvia, prejudicial to health, especially in densely-populated neighbourhoods.

To obviate this nuisance in a certain degree, several patents, at different times, have been obtained. Mr. Head, in 1806, discovered and patented the use of oxide of iron as a purifier; and many years afterwards, when Mr. Head's patent had nearly been forgotten, Mr. Phillips, of Exeter, took out a patent for purifying gas with oxide of iron, but this he only specified to be used in connexion with the ordinary wet lime purifier.

Mr. Croll, shortly afterwards, also obtained a patent for the purification from sulphuretted hydrogen by the use of oxide of iron in a dry lime purifier; and his patent also included, for the same purpose, the use of the metallic oxides of zinc and manganese, and the removal of ammonia by chloride of manganese, or sulphuric or muriatic acids.

Again, Mr. Croll is followed by Mr. Laming, who discovered that muriate of lime, when mixed with the metallic oxides, effects, by a compound decomposition, the removal of all the three ingredients at the same time, and, if necessary, in the

Digitized by Google

same vessel. And, yet again, Mr. Frank Hills shortly afterwards (in 1849) stepped in with a patent, which, though for a considerable time strongly opposed by the other patentees, was finally sustained by the Court of Exchequer, whereby he claims the use of what he called the hydrated and precipitated sesquioxide of iron for the removal of impurities from coal gas.

Other patents of a similar nature have since been obtained, principally bearing on the difference of iron in a hydrated and anhydrous state; but without further inquiry as to the relative merits of the different patentees, it may now be accepted as an established fact, the recognition of oxides, and especially oxides of iron, as reliable and effective agents for purification, and without cavil as to their supposed destructive as well as purifying properties.

In the method which has hitherto been most extensively employed, water, as formerly observed, is the first agent brought into action, the apparatus being the well-known washers and scrubbers already described; and following these for the removal of carbonic acid and sulphuretted hydrogen, are lime and oxide of iron purifiers.

It may here be observed that considerable difference of opinion exists as to the most economical method of using lime. Several gas engineers affirming that lime in a hydrated or ordinary slaked condition, is cheapest, cleanest, and throws least pressure upon the exhauster; while others, whose opinions are equally worthy of credence, say that lime made up with water to about the consistency of cream, and used in what is known as the wet lime purifier, gives most profitable results; that, although certainly dirtier, and the gas more difficult to pass, still the labour of shifting is less, the facility of a luting material is considerable, and the cost of lime no greater. There is no doubt that, whether from an idea of increased cost, or the facility of using a tier of dry lime in the oxide purifiers, wet lime purifiers are now almost obsolete in the metropolis; but the writer, although an enemy to the horrid nuisance of "Blue Billy," conceives that in works where water is plentiful and easily found, wet lime apparatus, when properly constructed, may be profitably employed as an auxiliary, although certainly not as an entire substitute for either dry lime or oxide.

Lime for use in the wet lime purifier is first made up with water in a mixer to the consistency of thick cream. The purifier is usually a large circular vessel, divided internally into semi-detached compartments, and filled with the lime water until the openings of the compartments are completely luted.

The liquid is kept in a continual state of agitation by revolving arms driven by machinery, and the gas is forced through

Digitized by Google

either by means of an exhauster or its own accumulated pressure. When foul, the lime changes to a bluish colour, and is then discharged and reduced to lime putty in the evaporating chambers.

When wet lime is employed in sufficient abundance, oxide of iron succeeding, is all that is necessary to complete purification, but, when wet lime is not employed, oxide of iron alone will not remove all the deleterious substances from which coal gas ought to be free before being sent to the consumer's burner.

This will be better understood when the different qualities which each of these bodies display when in action in the purifier are considered. Lime has a strong affinity for carbonic acid, and an affinity also for sulphuretted hydrogen, although in a slightly inferior degree; and thus lime has hitherto in many works, and until the last few years, in all sufficed for the complete purification from all impurities that must necessarily be removed.

Oxide of iron, on the contrary, has a strong affinity for sulphuretted hydrogen, and scarcely any for carbonic acid, and, consequently, only sulphuretted hydrogen is removed by its use.

It may be said, in answer to this, that carbonic acid is produced in great abudance when gas is consumed, and, therefore, although present in a certain degree, before combustion, its presence would produce no appreciably hurtful results; but the fallacy of this argument becomes perfectly plain when it is considered that the composition of pure coal gas is carburetted and bi-carburetted hydrogen, and therefore any foreign body, not being inflammable, must exercise a hurtful tendency, and deteriorate considerably the illuminating power. The atmosphere is not only attenuated by the withdrawal of oxygen by the flame, but even with perfectly pure gas the diffusion of the carbonic acid, although a heavy vapour, is perceptibly felt, and, how much more serious this would become with 25 in every 1000 parts of gas additional, can be easily understood.

Lime, therefore, or some other equally available alkaline earth, ought either to precede or accompany the oxide, and that when used separate, it ought to precede and not follow the oxide, can be easily demonstrated.

Hydrate of lime in the purifier, by the action of carbonic acid, becomes carbonate of lime—and part of this again, by the reaction of the sulphuretted hydrogen, becomes hydro-sulphate of lime, thus greatly assisting the subsequent action of the oxide upon the sulphuretted hydrogen; oxide of iron, on the contrary, if used first, would encounter both carbonic acid and the sulphuretted hydrogen, but would only retain the latter ingredient. The lime would only have done half its duty when fouled, and the oxide on which the extra work is entailed would last a cor-

Digitized by Google

respondingly shorter period. This rule may, however, in course of time be reversed, should the interests of gas companies then lie (as present appearances seem to denote), not so much in the saving of material as the careful securing of the sulphurous deposit, when, of course, the oxide will precede the lime, and the lime will only be used as a reserve, to prevent carbonic acid from escaping with the gas.

(Plate No. 4.)—The purifier is of cast-iron, and is generally square or oblong in form. The cover is wrought iron, riveted together in sheets, and the seal is made by means of a water lute round the edge of the purifier. The purifying material is carefully spread out on trays, and these are disposed in tiers or sets in such a manner as to leave a clear open space betwixt each succeeding layer, to allow the gas to diffuse itself thoroughly throughout the mass.

Lime, when once fouled, cannot be profitably renewed, and, therefore, every care ought to be taken in its disposal to bring it as equally and completely as possible in contact with the gas; layers deeper than 4 in. to 4½ in. being objectionable. Oxide of iron, on the contrary, may be renewed until it has absorbed from 50 to 60 deg., or fully half its own weight of sulphur, without seriously losing its efficacy, the depth of the oxide need have no other limit than the water lutes or the strength of exhauster will allow. But as, if the layer is deep and impenetrable, the gas has a tendency to force a passage at some particular point without diffusing itself in the mass, it becomes necessary to regulate the depth within a reasonable limit.

Light perforated plates of cast-iron make the best and most enduring trays for the use of oxide. Wooden trays are cheap and light, and, when lime is used, last well and give satisfaction. They are liable, however, to warp and twist with the oxide, unless exceedingly carefully seasoned, and there is supposed to be a danger of their destruction by the heating propensities of the sulphuret. Iron rods bound in an angle iron framing are sometimes used, but these cannot long sustain the oxidising influence of the acids.

Atmospheric revivification of oxide of iron is said to have been discovered, and was certainly first introduced into this country, by Mr. F. J. Evans, of the Chartered Gas Company, and beyond a doubt oxide, without it, could never have entered into profitable competition with lime. The process is simply spreading out the oxide or sulphuret in an open court, when the oxygen of the atmosphere in a few days precipitates the sulphur, and the oxide is again fit for use—and this may with common gas be repeated for a considerable length of time before the iron becomes chocked and useless. With cannel gas, however, the action is different;

Digitized by Google

it will run much longer in the purifier, but cannot be renewed so often. Care must also be taken to prevent it heating in the process of revivification, as the sulphurous fumes which arise are extremely dangerous, and if the fire is not quickly got under the consequences may be serious.

As Hills' patent expired in November 1863, the use of iron oxides are now free to all who choose to employ them, and there is no doubt that gas companies generally will appreciate the use of a substance for purification which is more valuable after being spent than in its original form.

Although Mr. Hills may, under his patent of 1857, try to prevent the abstraction of sulphur from manufactured oxides, its power is exceedingly dubious, and at any rate he has no claim on native ochres.

Should manufactured oxide be free and unfettered, it is not at all likely that raw material will rise in price, and in that case gas companies may yet have the satisfaction of seeing the item "purification" on the credit instead of the debit side of their balance sheets.

The usual tests for ammonia in gas are turmeric and litmus. Yellow turmeric becomes brown, and blue litmus, when first reddened with an acid, resumes its original colour when brought in contact with that alkali. Paper, dipped in a solution of acetate of lead, becomes black when exposed to the action of sulphuretted hydrogen, and carbonic acid may be detected by using a little strong caustic potass, which when dropped in a eudiometer with the gas to be tested will condense whatever carbonic acid it contains.

Station Meter.

The gas from the purifiers passes to the station meter, where the quantity made is registered. The station meter in principle is similar to the usual consumer's meter.

Gas-holders.—(Plates Nos. 6, 7, and 8.)

Gas-holders are invariably made circular, on the principle that the circle of all geometrical figures is the one that, with a fixed circumference or outline, is capable of enclosing the greatest amount of space. A gas-holder is made by riveting together light wrought iron sheets upon an angle iron framing, and in shape resembles a large inverted cup, the crown being either flat or the segment of a large sphere. It works in a circular water-tank, round which columns are erected that sustain guides at proper intervals, by which the gas-holder, when working, is supported, and a uniform easy motion imparted, indispensably neces-

Digitized by Google

sary for the steadiness of the lights supplied from it where no governor is used.

As it has long been well known that the larger the dimensions of a proposed gas-holder are, the cheaper can it be constructed per 1000 cubic feet of contents, and experience has amply proved that a large size is not incompatible with safety, the rule is now adopted to construct gas-holders as large as, from the nature and extent of supply, is deemed advisable. The Commercial Gas Company are now erecting one 206 ft. in diameter, and the engineer (Mr. R. Jones), in a recent report, states that this, when complete, will be the largest ever constructed. Another is also in course of erection at the Horseferry-road station of the Chartered Gas Company, the tank of which is 202 ft. diameter × 25 ft. deep. The excavation of this tank is a trench 12 ft. deep × 5 ft. in width all round; the sides are formed by ¾ in. B.B. Staffordshire plates, riveted, so as to be water-tight, by ¾ in. rivets; the bottom is covered with 1¼ in. cast-iron plates, and the cone inside is secured on the top by 3-16ths sheet-iron, underneath which is a layer of bricks and a thick bed of concrete.

At the Kennington-lane station of the Phœnix Gas Company there is a gas-holder 160 ft. diameter × 70 ft. high, which may here be noticed as peculiar in its construction. Contrary to usual custom, the columns are made of ⅜ in. and ¼ in. boiler plates, the diameter of each being 3 ft. 3 in. at the base, tapering to 2 ft. 8 in. at the top; the total height of the columns is 73 ft., and each column was erected in one piece.

Cast-iron girders round the top of the columns are dispensed with, 2 in. and 1½ in. round rods being used instead; and the gas-holder crown, when working, is entirely unsupported by any kind of framework whatever. To prevent collapse, however, should the holder ever come to the ground, a wooden frame upon brick piers was constructed at an almost nominal cost inside the tank, and this hitherto has proved a perfectly sufficient safeguard. Notwithstanding these deviations from usual routine, this gas-holder, erected in 1855 (by the Horseley Iron Company, from designs by Mr. Innes, the engineer of the Phœnix Gas Company), has hitherto given perfect satisfaction; the saving effected by using light wrought-iron instead of cast-iron columns, wrought-iron ties instead of cast-iron girders, and the entire absence of framing in the crown—usually a costly item in this size of holder—forming a considerable deduction from what would otherwise have been the total cost of construction.

In small works, single lift gas-holders are generally hung with counterbalance weights, and these, when capable of being conveniently shifted, serve to regulate the pressure, and thereby save the expense of a governor; but in larger works, where a

Digitized by Google

governor is employed, the dimensions of the gas-holder are calculated so that a uniform pressure may be thrown without the aid of a counterpoise; and this accomplished on the principle that, the weight of the holder being known, a quantity of water equal in weight will be sustained by it, and the depth of this column, depending on the superficial area of the holder, may be calculated when the diameter is ascertained.

It is, therefore, evident that the smaller the diameter compared with the total weight, the greater will be the pressure exerted, and *vice versâ*, gas-holders of a very large diameter compared with their depth frequently requiring weighting rings of iron attached to some part of their framing, in order to throw a column of water equal to the specified height.

It is now customary to make gas-holders of a large size on the telescopic principle—*i. e.* composed of two or more lifts; the inner ones carrying their own water-lutes, and working within each other, similar to the various divisions of a telescope.

By this means ground, when scarce, is greatly economised, and the saving in tank excavation and building reduces the ultimate cost considerably below the sum required to erect a gas-holder of equal capacity on the single lift principle. The lutes are liable to become frozen in extremely cold weather, but this may be guarded against by the introduction of a steam-pipe, which will always prove a sufficient remedy when a necessity arises for its use.

The choice of a position for a large gas-holder, where a choice can be had, requires careful and judicious inquiry on the part of the engineer. Rocks and water-springs ought, if possible, to be avoided; the first largely increasing the cost of excavation, and the latter endangering the stability of the walls of the tank, besides seriously impeding their construction. A stiff loamy soil is evidently preferable to a sandy or porous one, assisting, as it must do, the clay-puddling, which is generally found necessary to keep the tank water-tight. The only reason to the contrary being, that should a good workable sand be found, it may be used in the mortar and concrete, and thus partly effect a saving in the cost of building the walls.

When a pressure of gas or atmospheric air is first introduced in an empty holder, an instantaneous effect is observable on the crown and side plates. The crown plates are quickly forced out, and the gas-holder generally begins to have a smooth, rigid appearance, very different from the uneven look it presented when simply supported by the framework underneath the sheets.

It is thus abundantly evident that the true support of a gas-holder crown when working is the pressure of gas inside, and although certainly advisable to construct a light supporting frame-

Digitized by Google

work, still this only becomes useful when the gas-holder is at rest, and should in no case be complicated or expensive. There is no doubt that with sheets of sufficient thickness in the outer circle of the crown and top rows of the circumference, a very light framing indeed ought to be sufficient as a safeguard under any ordinary circumstances.

Many gas companies are still without the advantages of having storage capacity equal to twenty-four hours' consumption in the depth of winter, and yet engineers unanimously agree that money laid out in this way is judiciously expended. It saves retorts and stokers' wages. It reduces the per-centage of fuel, and prevents the danger of a short supply in the depth of winter. In fact, it goes far to produce a substantial uniformity in the management of a company which invariably commands success.

Governor House.—(Plate No. 9.)

In several of our largest gas-works the distribution to consumers is managed by having a separate main pipe for each of a number of districts. Upon these mains, at their exit from the works, valves are placed, each valve having a revolving pressure indicator attached, the paper of which is graduated into inches and tenths, and marked with spaces corresponding to the twenty-four hours of the day.

These are entrusted to an experienced valvesman, whose duty it is, by gradual opening and partly shutting them, to give out pressure in the various hours, corresponding to instructions he receives from the superintendent.

In more modern works an improved system has been adopted, and the gas is there sent out by means of a self-regulating governor.

This is a miniature gas-holder, with a cone hung by its apex from the centre of the crown, and, similar to the others, works in a water-tank up through which the inlet and outlet gas-pipes are carried.

These pipes may be either concentric—as they are now usually made, to save space—or they may be carried up side by side; but, in either case, the inlet must be exactly in the centre of the tank, and cast in such a way that the neck, when bored out, shall fit and form a gas-tight joint with the larger extremity of the cone.

Two methods are adopted of balancing the governor so as to throw of its own weight a certain fixed amount of pressure, being the minimum at which the distributing mains are intended to be wrought. One plan is the ordinary counterbalance weights, which, of course, are capable of readjustment at any time, and

Digitized by Google

are otherwise very convenient. The other, besides having a neater appearance, imparts a much more delicate action to the holder, the friction of string and pulley, or cycloid arms, being entirely done away with. By this method the superfluous weight of the governor is buoyed up by an air-chamber underneath the water, the dimensions of which are calculated on the principle that as a cubic foot of water weighs 62.35 lb. or thereby, when weighed in air, so a cubic foot of air, imprisoned underneath water, will exercise a buoyancy equal to the weight of its own bulk of water, and, in this way, the weight and dimensions being known, the adjustment becomes a matter of easy calculation.

As the gas is turned on the bell, or gas-holder, begins to rise, and this would continue until the base of the cone, coming in contact with the seat, would effectually prevent further supply; but, at the same time, a counteracting influence is exercised by the consumption going on in the district, thus withdrawing the gas as it enters, and thereby keeping the bell suspended midway, alternately rising, as the supply exceeds the demand, and falling as the consumption increases. Weights calculated by the area of the holder to throw a certain additional pressure must be added as the evening lighting begins, and these are cautiously withdrawn as the night advances and daylight gradually begins to appear.

The Test-Room, Photometers, &c.—(Plate No. 9.)

By testing the gas is meant trying its illuminating power and freedom from impurities, and the test-room is, in fact, a laboratory in which these and other experiments connected with the manufacture are conducted. Of the two principal ways adopted for determining the illuminating power, the test, by the Bunsen or Evans's Photometer, although not by any means unquestionable, is generally admitted to give most reliable results. The process is to compare the light given by a 15-hole Argand burner, consuming, with a 7 in. chimney, five cubic feet per hour, with a spermaceti candle consuming 120 grains per hour, by placing them one at each end of a rod, which, for convenience in calculation, is generally 100 in. long. The principle of the test is, that a circular light, throwing out its rays equally, illuminates a complete circle, and that the amount of light given by one burner compared with another is as the squares of the diameters of the several circles illuminated.

In testing, the gas and candle being lighted, all other natural or artificial light is excluded, and a movable prepared paper disc is made to slide on the graduated rod until the junction of the two circles is found. This is known by the transparent centre of

Digitized by Google

the paper disc, showing an equal shadow on both sides, when the figures marked on the rod calculated on the principle before explained show the relative value of the two lights.

The above is the well-known Bunsen Photometer, which, when a system of averages is adopted, gives a result very closely approaching perfection. To remedy, however, some of its defects, Mr. Evans, some time ago, patented an improved arrangement, whereby the lights and paper indicator are shut up in a close portable box, by which means a test may be had in the open air, or in any ordinary room or hall, without the necessity of excluding other necessary lights, or adopting precautionary measures against reflexion from objects in the vicinity of the operator.

Another way of trying the gas is by the test eudiometer. This is a glass tube, bent at one end and closed at the other, graduated into 100 divisions, the Zero marks being just above the bend, and the numbers extending upwards to the close end of the tube, and into this a pipe is inserted in such a way that, when the gas is turned on, the air may be expelled by the action of the gas as it fills the tube. When completely full, and the air thoroughly expelled, the bent end of the tube is filled with water, and a small portion of bromine introduced, which has the effect of condensing whatever hydro-carbons or light-giving components the gas may contain. The bromine is then removed by the action of a strong solution of potass, applied in the same manner as before, after which the amount of condensation may be read off on the graduated scale of the eudiometer.

The specific gravity of the gas being known before being tested, the specific gravity of the remainder is then taken, after which the specific gravity of the condensed matter may be easily ascertained, the difference in actual weight having been caused by the withdrawal of the portion of condensed gas; and it is then found that the amount of condensation, multiplied by the specific gravity, gives a result agreeing very closely with the photometer in reference to sperm candles, consuming 120 grains per hour.

Chlorine, fumings of sulphuric acid, and, up to a certain temperature, common naptha, have the same effect in condensing the hydro-carbons; but neither on this nor its twin brother, the explosive test, can the least reliance be placed, unless the experiments are conducted by the hands of an experienced chemist; and engineers generally prefer the simplest method of arriving at a result, which, after all, is only useful as an approximation to a problematical value.

Digitized by Google

Gas Meters.—(Plate No. 10.)

From the governor the gas traverses the street mains until it arrives and is measured at its destination by the consumers' meters, of which there are two kinds, commonly known as the wet and the dry meter. In the wet meter the measurement takes place by the revolutions of a cylinder divided internally into four spiral compartments, and in the dry by leather diaphragms, which are filled and emptied alternately as the gas passes through them on its way to be consumed at the burner. These motions are conveyed by light clock-work machinery to the index, and this being read generally once a quarter by the company's inspector, the quantity passed is found by deducting from the figures indicated those registered at the last reading.

A recent Act of Parliament makes it compulsory that all meters now fixed for use shall be stamped with a Government stamp, guaranteeing correctness, and this among wet meter manufacturers has called into extensive use a number of patents for the correct preservation of the water level, upon which the registration depends. Among these may be mentioned, as specially noticeable in a scientific point of view, the patents of Mr. Esson, of Cheltenham, and Mr. Allan, of Perth. They were both obtained about the same time, and are identical in principle, a familiar example being that of the Bird fount, by which water hangs suspended in a vacuum until relieved by the presence of a gaseous body; and the action of the meter is such that, when the water in the cylinder evaporates below the correct level, a pipe is unsealed, which admits a portion of gas to the top of the fountain, and immediately a corresponding quantity of water is liberated to make good the deficiency.

A non-tilting valve on the same principle has also been patented by Mr. Kay, engineer to the Dundee Gas Company, and, so far as fraud by tilting is concerned, this is about the best preventive ever experienced. Mr. Saunders, of Dublin, has also obtained a patent for a compensating meter, on the principle that a body submerged among water elevates the level to a degree equal to its own bulk, and, if properly manufactured, the action of this meter is undoubtedly sound, and ought to give perfect satisfaction.

In dry meters the gas is admitted, and makes its exit by means of port holes closed by a valve similar in action to the slide valve of a steam-engine. The great evils however, hitherto attending their use have been the liability of the diaphragms to become porous, and the wear and tear causing the rubbing surfaces of the valves to become unsound; both contingencies, of course, allowing gas to pass unregistered.

Digitized by Google

In Defries' dry meter there are three compartments, composed principally of leather, and having the action and measurement of a cone. This, it is supposed, tends to increase the steadiness of the lights; but, however this may be, it is generally found that the leather, however carefully manufactured, has a tendency to give way at the crease marks made by the filling and emptying of the diaphragms.

The Meter Company's meter of more recent construction has only two diaphragms, and the manufacturers obviate to a certain extent the liability to become porous by employing a framework of tin-plate at the ends. The valves, however, have the same tendency to become unsound as the others, and this it is that causes nine-tenths of the annoyance felt by gas companies in the use of dry meters.

The last part of the gas apparatus is the gas burner; and this, although apparently so insignificant, really has an important bearing on the economy or otherwise with which gas is consumed. Thus, different qualities of gas require a different class of burner for efficient consumption, poor gas giving most light when burned by a large Argand, whereas a gas rich in hydro-carbon is most economically consumed by an ordinary sized fish-tail burner.

This is caused by the action of the atmosphere on the carbon and hydrogen, of which the gas is composed, and it is found, as before explained, that with common gas the maximum effect is produced when the gas, issuing from a comparatively large orifice with a light pressure, forms a thick, yellow flame, the carbon being thus thoroughly, but, at the same time, leisurely consumed.

With cannel gas, on the contrary, when carbon is so plentiful, the orifice, to produce the maximum effect, may be heavier than the other, but this must not be carried beyond a certain limit, and, as a rule, it is understood that the greatest amount of light is produced with the minimum quantity of gas used when the flame, without any trace of smoke, is yet just on the verge of smoking.

DISCUSSION.

The CHAIRMAN stated that Mr. Wilson, the author of the paper, was unable to attend, having lately been appointed engineer to the Para Gas Company, and being on his voyage out. Mr. Wilson had not, in consequence, had time to prepare the diagrams, but the Honorary Secretary had done so since his departure.

Mr. PADDON said, as the paper embraced such a wide range it was necessarily more general than particular in its treatment

Digitized by Google

of the subject. He did not think it was any disparagement to the paper as a whole, to differ from it in a few particulars. It was stated in the early part of the paper that the yield of coke per ton of coal did not much vary, but in his (Mr. Paddon's) experience he had found as much difference as fifty per cent.; if necessary, he would at a future meeting give the actual results from the use of certain coals. There were other matters in the paper with which he could not coincide; but he would at present refer to one only, and that was the means preferred by the author for condensing gas. Considering that gas was not always alike as it came from the hydraulic main, and the great difference between summer making and winter making, he thought that the best form of condenser was that which, after giving the largest amount of cooling surface with the least resistance, allowed modifications to be made according to different circumstances. The one mentioned by the author would not do that. For small works there could be nothing better than the ordinary pipe condenser; but for large works, the annular condenser, properly constructed, would be found more advantageous.

Mr. THORMAN said that he had recently erected some scrubbers on the principle adopted by Mr. Mann, the engineer to the City Gas Company, which were most efficient, and that 12-ounce liquor could be obtained from them at one operation.

Mr. E. RILEY said, the quantity of ammoniacal liquor produced was in proportion to the surface the gas was exposed to. Although ammonia was not absorbed so quickly as hydrochloric acid, there was certainly a certain amount of sulphur escaped, which was allowed by the Act of Parliament, and he saw no reason why the same should not be applied to ammonia. The plan referred to seemed a very efficient one.

Mr. DOUGLAS said that the object was to distribute the water equally over the scrubber, which was a difficulty, and he thought the plan adopted by Mr. Mann, in a great measure, overcame this difficulty. With reference to the use of exhausters, he was of opinion that they should always be used in small works as well as large, and that gas was greatly improved by their use, as the closer you exhausted to the point of vacuum the better the gas, as the better gases were thus prevented adhering to the retorts. He preferred a setting of five retorts to any larger number; he thought better results could be obtained, as the heating was more under control than was the case in larger settings.

The CHAIRMAN remarked, that at the new works of the London Gas Company there were nine retorts in a setting.

Mr. R. M. CHRISTIE asked Mr. Douglas if he could inform the meeting (he having stated it was desirable to use exhausters)

Digitized by Google

what daily or weekly quantity should be made to make the erection of an exhauster desirable. Mr. Paddon had mentioned that he used cylinder exhausters, but he (Mr. Christie) did not think they were efficient.

Mr. DOUGLAS. About 40,000 per day.

Mr. PADDON said, that the three-cylinder exhauster referred to had been in constant use for three years, and the only evidence of wear and tear upon it was that occasioned by the friction of the slide and piston rods. He had been told it would take much less power than one of Beale's, and he was sure it was much more durable and did its work better. The only objections were, that it took up more room and was dearer at the outset than Beale's. He believed it was equally as steady, and oscillated as little as any other. The oscillation was probably about three-eighths of an inch, and that he believed could be prevented by more delicately arranging the slide valves, but he did not consider that at all necessary.

Mr. R. M. CHRISTIE said, why he particularly alluded to the exhausters of the Brighton and Hove Gas Works was, that he went into these works some short time ago, when the oscillation of the exhauster was at least three inches, and he was told by the foreman that it sometimes reached six inches, which he thought was most objectionable.

Mr. PADDON said (in reply to Mr. Christie), that he looked at the exhauster almost every day, and if ever the foreman saw it oscillating six inches, it was more than he had ever seen. He believed it might have done such a thing as oscillate two inches, but that would be caused by the washer being a little overcharged with water, and that of course would affect any kind of exhauster.

Mr. DOUGLAS thought the oscillation was more apparent when the exhauster was driven quickly than it was when driven slowly.

Mr. PADDON said that the oscillation of the exhauster was generally exaggerated in appearance by the smallness of the gauge tube, in comparison with the pipe leading to it.

Mr. BURTON said, the oscillation of the cylinder exhauster could be obviated by using a cam. He thought the larger they were and the slower they worked, the less would be the oscillation, which was just the reverse of Beale's, and, as regarded room, it would take up less than Beale's.

The CHAIRMAN said, there were several interesting and important points that had not yet been discussed: such as cylinder *versus* rotatory exhausters; the manufacture of gas from wood or peat; or how far any experiments had been made with petroleum gas; all which might be enlarged upon at a future meeting.

Digitized by Google

March 7th, 1864.

H. P. STEPHENSON IN THE CHAIR.

ON THE MANUFACTURE OF COAL GAS.

By A. F. WILSON.

ADJOURNED DISCUSSION.

MR. R. M. CHRISTIE opened the discussion by observing that the paper of Mr. Wilson was a very fair general description of gas manufacture, rather than advocating any particular construction of apparatus. Mr. Wilson, after referring to the retort-house, proceeded to advert to the retorts, which was one of the most important matters in connexion with gas manufacture. As to the number of retorts in one bed, it was, perhaps, not fair to come to any conclusion until the discussion was completed. What engineers required upon that point was some definite principle as to how the retorts could be heated with the least possible amount of fuel. The very general number in London was seven to one furnace; the Imperial had nine, the Chartered eight, and the London Gas Company nine, but those who had adopted the extreme number of ten or twelve ought to be able to show that fuel was saved, which he very much doubted. The Phœnix and Commercial used only seven, and were heated as economically, as far as fuel was concerned. The next point was iron *versus* clay retorts. The respective merits of iron and clay retorts was a question some six or seven years since, but since that period clay retorts had altogether superseded iron, except in small works. One great advantage with clay retorts was that they did not expand or contract so much as iron, lasted very much longer, and retained their full working power almost to the last. As to the best shape of retorts, that was a question about which engineers differed. Some advocated circular, some D-shaped, and others oval retorts. He had no doubt either of those shapes might be used with advantage, but he preferred a circular retort, or one without any sharp corners. The next question was the mode of setting the retorts. He thought that

Digitized by Google

clay retorts, supported at intervals of six and twelve inches around the whole length, was universally acknowledged as the right system. Although in small works short retorts must be used, yet there could be no question long retorts had the advantage. Regarding Mr. Anderson's patent of using coal and tar for fuel, he would ask Mr. Anderson, who was present, to give the information to the meeting. Another point was, whether it was better to use one large chimney or a series of small chimneys for giving draught to the retorts. In some gas-works it was compulsory to have large chimneys, but, under other circumstances, it was yet a question whether the large were better than small, although both were good in their way. As to the best form of washers and scrubbers, those adopted by Mr. Mann at the City Gas-works certainly produced a very strong liquor at one charge (14-oz. liquor). Sulphuric acid was often used in the washer, and the sulphate of ammonia that was manufactured from the result was a very valuable product. After having thus passed the gas through a washer, it became necessary to further purify it from carbonic acid and sulphuretted hydrogen, which was done by the use of lime or oxide of iron. The wet lime process was used almost universally some few years since, but, from the excessive nuisance of the waste produced, it had been abandoned, although the process itself was a valuable one, and very effective. The oxide of iron process was now being almost universally adopted. By the gas passing through the oxide of iron, sulphur was extracted, and when the oxide of iron was taken out and revivified the sulphur was liberated, and the oxide of iron was the same as before it was used. This was a very cheap means of purification.

Having explained by diagram a dry lime purifier, he observed that there could not be much discussion upon it, as the opinion was general that no better form could be adopted. Before the gas went through those different purifiers, an exhauster was almost universally used, and perhaps the most general in use was that known as Beale's; which might be called an almost perfect exhauster. Another form of exhauster was that patented by Mr. Anderson, and another was that known as the cylinder exhauster. At the last meeting a discussion was raised upon the question of a cylinder exhauster; he objected to that form of exhauster because he did not think it produced a perfectly uniform exhaust, and another objection to Mr. Paddon's form of exhauster (cylinder) was that it was very much more expensive, while no better results could be produced than by the very simple exhauster of Mr. Beale's. The next point was as to the description of engine and boiler. There could be no question that the best form to be used was that which was the most eco-

Digitized by Google

nomical for fuel, being otherwise efficient. Gas-holders were made of several forms, single lift or telescopic. The outer sheets, he might mention, had nothing to do with the gas-holder itself, but the series of framework inside was the important part. Single-lift gas-holders would generally be constructed, being less complicated and less liable to be affected by frost, if it were not for the expense, as each gas-holder must have a tank, the telescope holding double the quantity with one tank. The want of space was the reason that gas companies in London were compelled to use telescopic gas-holders. A question in connexion with gas-holders was whether the top should be supported by a frame, or whether it should be plain and flat. He (Mr. Christie) had constructed both, but he did not think that the prejudice against flat roofs was correct, though many, from bad construction, had turned out failures. At all events, a flat roof-holder was constructed at the Phœnix some eight years since; it was 160 feet in diameter, and there had not been the least thing wrong with it during the whole period since its construction, likewise several erected by himself working perfectly satisfactorily. With reference to the size of gas-holders, he could not help thinking there was a great objection to having them so large as was now talked of, over 200 feet diameter. There was no question that the ordinary brick tank was the cheapest in London because of the blue clay foundation, but, wherever this extraordinary favourable ground was not met with, other material than brick might be more safe and economical.

As to wet and dry meters, each maker contended that his own was the best; but there was no doubt, that when the wet meter was properly charged with water, it was almost a perfect measuring instrument, the greatest difficulty being to keep the water at a uniform water-line. The last new meter was one manufactured by the Meter Company. It was an ingenious device; it had a disc-float, which kept the water to a certain level. The dry meter was a very good machine; in fact, he could scarcely give a preference to the one or the other. As regarded the best means for charging for public lighting, the general plan was to give a certain pressure, and calculate the number of hours the lights were burnt. It was thought that gas companies by these means cheated; all he could say was, let the Board of Health, or other local authorities, have their own way, for there could not be the slightest objection on the part of gas companies to having a gas-meter fixed on each public lamp, provided the local authorities chose to pay for them.

Mr. Paddon would not like it to be thought that he had no reasons for the preference which he gave to the exhauster with three cylinders. First, it was not so likely to break down or get

Digitized by Google

out of order as others, and it would last much longer. It also worked with much less slip of gas, and required less power to drive it. These were important advantages, and fully justified the greater original cost and the extra space it occupied. As to the oscillation referred to, he certainly could not see how it could affect the retorts, as the condenser was placed between the retorts and exhauster, and there should always be a slight pressure on the retorts. He had never known the oscillation extend to the retorts. If any one thought it worth while to have no oscillation, it would be found that no mechanical arrangement would so well attain that end as three cylinders worked from a common shaft, with cranks set at angles with each other of 120 deg. No more perfectly continuous delivery of gas could be given than that done by a three diaphragm dry meter, and the mechanical principle was analogous in meter and exhauster.

Mr. Mann said that when making 2,000,000 cubic feet of gas per day, he could get through each scrubber 1000 gallons of water, and raise it to 10 oz. strength, but as the contract was to supply 7-oz. liquor at a certain price, he was anxious to make as much 7-oz. liquor as he could. The efficiency of a scrubber depended upon the way in which the water was distributed. The difficulty he had always found was how to keep up a good distribution of water with a series of small holes, because if there were a large number of small holes, there must be sufficient water to keep them all going. To get all the holes to act, the water must be flushed in, and consequently it had to be pumped over and over two or three times to get the strength. Mr. G. Lowe was the first who took a patent for a self-acting distributor, which was a modification of Barker's mill, but the large quantity of water necessary to keep it going was too weak to be called ammoniacal liquor after passing once through, consequently it had to be pumped over again; besides, the holes were continually being stopped. Mr. Hills invented a tumbler for flushing the water into the self-acting distributor of Mr. G. Lowe, in such quantities as would be raised to the required strength by passing once through the scrubber, but the evil of the holes stopping still remained; but the plan he (Mr. Mann) had adopted for four years past worked remarkably well. That it was a perfect distributor of the water was certain, for 1000 gallons per day would pass through and be raised to above 9 oz. strength. The water was measured into the scrubbers by one of the regular Water Company's meters, therefore the quantity of liquor made was known. The only difference in the arrangement of the coke was its being continued up some six or seven inches higher than the set off in the plates forming the top of the scrubbers, so that the water was always flowing down the

Digitized by Google

sides. In other scrubbers the sides were vertical from bottom to top.

Mr. G. Anderson was of opinion that there was no limit to the number of retorts to be heated by one fire, for the simple question was as to the setting of the retorts, so as they could be equally heated. As a matter of principle, the more retorts that could be equally heated, the more economical it would be. With a small number of retorts it was not often that the heat was utilised. He had proved by experiment that by the use of clay retorts alone there was a loss of heat, because they were bad conductors; and therefore it was judicious to have in combination with clay retorts a given number of iron retorts, which were good conductors. He knew there was a prejudice against iron retorts, but it had arisen out of previous modes of setting, by which they got destroyed. He had been induced to burn tar from the low price he realised by selling it. Burning tar he knew was no new thing, but the difficulty had been its destruction to the retorts. As it was a serious thing to give the tar away, after some experiments he decided upon a furnace, which was simply an inclined plane of brickwork, in which he successfully burnt tar. A large quantity of oxygen was admitted to the furnace, the retorts were heated with tar alone, and with a total absence of smoke, and a good duration of the retorts obtained; it was found that 70 gallons of tar were equal in heating power to a chaldron of coke, which made the tar worth about 2d. per gallon. He generally arranged to burn the tar when coke was dear. He considered that Mr. Mann's scrubber was a perfect machine, for small works it would be expensive, but that, in large works was no object. In his works he used washers and sulphuric acid, and no scrubbers. He did not think the pressure was so much an objection since exhausters were used. His impression was that a washer was the most effectual mode of extracting ammonia from gas (explained by diagrams). He thought that Beale's exhauster was a very good one, but it required a great deal of power to work it, on account of the amount of slip. They knew as they increased the speed they must increase the power in a greater ratio; so they found practically when they required high speed they had to employ very great power. There was an enormous disparity between the power employed and the effect produced, and it would be found, if they calculated the displacement which should be due to the speed of the machine, they would have a much larger result than the actual work. He had made a single cylinder exhauster, which completely answered his expectations. Gas was an elastic body, and the exhauster being a long way from the retorts, the action at the retort would not be known, whether the exhauster was at work or not. The half-inch oscillation

Digitized by Google

could be reduced to *nil* by partially shutting down the inlet valve. The simplicity of his exhauster was its chief recommendation. It was a pump in the shape of a reciprocating engine. Mr. Beal's exhauster was brought out as a rotatory steam-engine; it did not succeed as a steam-engine, but it did succeed as an exhauster. He was glad that Mr. Christie was beginning to see that gas-holders did not require a large amount of framing in the crown, for he (Mr. Anderson) thought they were a great deal better without framing, and his reason was this: that when inside a gas-holder of 160 ft. in diameter filled with air, he found no part of the sheeting rested upon the framing. In some gas-holders the sheeting was attached to the frames, the result of which was that the sheeting was torn. The Great Central Gas Company, with which he had been connected, put in no crown framing, and a great many people found fault with it at the time. The simple question was to construct the top curb sufficiently strong to resist the greatest force brought against it. He believed the only force to be encountered was the wind. (He then explained by diagram the reason there should be no trussing in the crown.) The only other point to which he would refer was as to the mode of charging for public lights. He thought there was an objection to metering every thirtieth or twentieth light, which was, that the light without the meter would burn more gas than the light with the meter; they should either be all metered or none metered. But, at the same time, he thought the Local Boards ought to have some control, so as to know that they got what they paid for. If an experiment were made in each case to see what the metered light burned and the unmetered light burned, he thought gas companies would have no cause to complain.

Mr. HARRIS said that the gas-holders referred to by Mr. Anderson as having no trussing in the crown were telescopic-holders, and he had never known any holders to work better.

Mr. R. M. CHRISTIE inquired if Mr. Harris had derived any advantage from setting a large number of retorts in one bed.

Mr. HARRIS could not say what advantage was gained, but he used eleven retorts in a bed, and they worked very efficiently.

Mr. ESSON said that his fuel account would possibly be considered extravagant, when compared with the low rates that were obtained in the metropolitan companies. There were, however, advantages under the higher fuel rates, otherwise their annual results would not bear so favourable a comparison as they did. He had abandoned the hydraulic main, and substituted well-fitted throttle valves, which had now for several years been found to answer better. There was uninterrupted gas-way between the interior of the ovens, when in action, and the ex-

Digitized by Google

hausters, and no trouble from carbonaceous deposit. The scrubbers were of comparatively small diameter, and nearly filled with small stones. The gas was admitted into a chamber at the base, and a much larger than usual stream of ammoniacal liquor from the tar-well continuously pumped in at the top, which passed downwards and onwards again to the tar-well. By means of this circulation the ammoniacal liquor was raised to eighteen and twenty ounces of strength. The gaseous exhalations from the tar-well and condenser cisterns were drawn off by an exhauster and utilised. The whole of the ammoniacal products were converted into sulphate of ammonia, without nuisance, and twenty-six pounds of the sulphate obtained for every ton of coal carbonised. He had tried Jones's and Beal's exhausters, and had seen Anderson's and others at work. He preferred Jones's.

Mr. R. M. Christie said the quantity of sulphate of ammonia mentioned by Mr. Esson was large, and inquired if he used any particular coal?

Mr. Esson said he used Derbyshire coal.

Mr. Perry F. Nursey said that during the preparation of his recent paper on Fuel, the manufacture of gas from peat came under his notice. Some interesting experiments had been made by Mr. Robert Jones and Mr. F. Versmann, F.C.S. (the former engineer, and the latter consulting chemist, to the Commercial Gas Company), with condensed peat, which was manufactured by Buckland's patent process as described in the paper referred to. These experiments were made at the works of the Commercial Gas Company, in a set of experimental retorts generally used in determining the value of gas coals, and the results thus obtained were given in the following Table A:

Table A.—1 Ton of Condensed Peat yields:

Locality of Peat.	Cubic feet of purified gas.	Illuminating power in sperm candles.	Percentage of olefiant gas.	Cwts of coke.	Gallons of tar and ammoniacal liquor.	Percentage of carbonic acid in raw gas.
Belfast	10.500	15.65	6	8	64	10
Creevelea	9.240	18.75	7	8¾	63	9
Welsh	11.000	22.50	8	7	60	10

In order to compare the value of peat with that of coal, Mr. Versmann drew up the Table B, which gave the practical results obtained with a variety of coals:

Digitized by Google

TABLE B.—1 Ton of Coal or Peat yields:

COALS.	Cubic feet of gas.	Illuminating power in sperm candles.	Cwts. of coke.	Gas per ton, equal to lbs. of sperm.	Sperm, corresponding to gas of Boghead Cannel, No. 2, equal to 100.
Staffordshire	7.100	12.42	13½	302	13.6
Derbyshire	7.600	11.71	17	305	13.7
Himwick	9.300	11.50	14¼	366	16.5
Ravensworth	10.100	13.30	13½	460	20.5
Lochgelly	8.000	18.00	13	494	22.2
Pelton, Newcastle	9.700	15.60	14	519	23.3
Ramsay's „	9.700	16.60	13½	552	24.8
Derbyshire Cannel	8.500	20.60	15	600	27.0
Wearmouth	11.900	15.96	13¼	651	29.3
Wigan Cannel	10.000	20.00	13¼	686	30.9
Newcastle „	9.800	25.00	13¼	840	37.8
Wemyss „	11.600	31.75	14	1262	56.8
Lesmahago „	10.500	40.00	10	1440	64.8
Boghead „ No. 1	12.500	40.00	8	1713	77.1
„ „ „ 2	13.000	48.00	6	2222	100.
CONDENSED PEAT.					
Belfast	10.500	15.65	8	563	25.3
Creevelea	9.240	18.75	8¾	594	26.7
Welsh	11.000	22.50	7	849	38.2

In estimating the value of a material for gas making, there were several considerations to be kept in view. The main question was the quantity of purified gas and its illuminating power. But the yield of by-products, as Mr. Versmann observed, was by no means unimportant, therefore the quantity and quality of coke and fluid products—such as tar and ammoniacal liquor—must be taken into account, and also the expense in purifying the gas.

Referring to Table B, it would be found that the quantity and quality of gas did not stand in any fixed relation. It was therefore necessary to express those two figures in *one* number, which was best done by calculating the weight of sperm, to which the quantity of gas corresponded, obtained from one ton of material. That was shown in column 4 of Table B. But, in order further to facilitate a comparison, Mr. Versmann took the value of the best and most expensive, Boghead Cannel 2, as a unit 100; and in the last column of Table B he reduced the value of all those different coals and peats to that standard. It would be observed that a comparison of peat with coal in that respect was greatly in favour of the former. The list of coals included fifteen different examples, six of which, at least, were

Digitized by Google

so superior as never to be used unmixed. Under ordinary circumstances it would not do for gas-works to send out a 20-candle gas, as the Act of Parliament only required a 12-candle light.

The Belfast and the Creevelea condensed peak stood better than seven samples of coal out of a series of nine; and the Welsh condensed peat was superior to not only all those nine samples, but even to the best Newcastle coal. In fact, the Welsh peat was inferior only to the very expensive cannel coals, which yielded a large quantity of gas of high illuminating power, but which were never used alone in gas-works.

Peat did not yield such large quantities of coke as coal; but peat-coke was superior to common coke, on account of the absence of sulphur. All gas-coke contained a sensible quantity of sulphur, which often interfered with its application. The coke obtained from condensed peat was hard and dense, resembling much more wood-charcoal than gas-coke, and would fetch a much higher price than the last. The perfect absence of sulphur in peat would allow of the application of peat-coke in many cases where gas-coke could not be used.

The following conclusions were, therefore, to be drawn from the foregoing experiments and statements:

1st. Peat, in the air-dried state, could not be used for gas purposes; although a good gas was produced, and in large quantities, still the purification would become too expensive, and the residue left in the retort would be perfectly valueless.

2nd. Condensed peat yielded, under all circumstances, the most favourable results if compared with coal. The quantity and quality of peat-gas were superior to almost any coal-gas; the quantity of coke was smaller than that of gas-coke, but its value was so much higher that hardly any difference would result in that respect. The purification of the peat-gas was more expensive than of coal-gas, a larger quantity of quicklime being required; however, that was the only objection, and it would be more than counterbalanced by several important advantages, one of which was, that the peat was worked off much quicker than coal, by which considerable saving in labour and firing was effected. The absence of sulphur in peat facilitated the purification of the gas, and greatly increased the value of the coke. Condensed peat, therefore, appeared to be a most valuable material for gas purposes.

Mr. Douglas said that, about thirteen years ago, two of Beal's 40,000 exhausters were fixed at the Bankside station of the Phœnix Gas Company; they had not been removed since, and the only repairs necessary were new friction rollers. They worked very satisfactorily. There were six of Beal's exhausters fixed at the Vauxhall works of the Phœnix Gas Company.

Digitized by Google

These were nominally for 40,000 cubic feet per hour each; but he did not approve of driving them fast, and seldom worked them more than 25,000 an hour. The oscillation at Kennington, through 1000 yards of 24-inch main, was just perceptible. Mr. Mann's scrubber was the best he had seen, and if the liquor could be got up to the strength required, by the water passing only once through it, much expense and trouble would be saved. But as he had a doubt of this, he would be glad if Mr. Mann could say how much liquor he sold per ton of coals carbonised. At Vauxhall he (Mr. Douglas) made over twenty gallons of 8-ounce liquor, and expected to make five or six gallons more with more perfect apparatus. But he pumped it over and over until the strength was sufficient.

Mr. Mann could not say the quantity of liquor sold per ton of coals carbonised. He had tested the liquor through two pairs of scrubbers; the first pair would raise the water to a strength of 10 oz., whereas the water that once passed through the second pair of scrubbers would not be 3-oz. strength, and this was with the least quantity of water that could be allowed to flow through them, which showed that the first pair must have taken out nearly all the ammonia.

March 21*st*, 1864.

A. WILLIAMS IN THE CHAIR.

ON THE MANUFACTURE OF COAL GAS.

By A. F. Wilson.

ADJOURNED DISCUSSION.

Mr. Latham said that several matters connected with gas manufacture and distribution had received very little attention during the discussion. The subject of meters and the best mode of public lighting had been scarcely mentioned.

During the discussion it had been generally agreed that exhausters were very useful; yet some members had pronounced themselves in favour of the reciprocating principle, and others in favour of the rotary principle. He was in favour of the reciprocating principle, because it had always been found that when a reciprocating and centrifugal pump were placed to work under the same conditions, that the per-centage of duty was very much

Digitized by Google

in favour of the former. When he said he preferred the reciprocating exhauster, he referred to it as requiring less power, all other things being equal, to perform a given amount of work; yet there were circumstances when, from its size and the facility with which it could be worked, the rotary exhauster could be used with advantage. An objection had been raised to Beal's exhauster, because it was originally brought out as a steam-engine; but that could not be taken as an objection. The member who raised that point must have lost sight of the principle that any machine from which power was derived, and which was impelled by a fluid of any description, would, if the action of the machine was reversed, exhaust or raise a corresponding amount of that fluid. Another objection that had been raised against Beal's exhauster was the rapidity with which the gun-metal packing wore away or became corroded. He would suggest that aluminium bronze might be substituted in the place of gun-metal for the packing and bearings in that machine, or any other machine where we had to contend not only with the wear and tear induced by friction, but also with the chemical action of the gas and the compounds present in it. He thought it might be substituted with very great advantage, as it would resist chemical action, and because it had a greater tensile strength than gun-metal, and could resist compressive action better than cast-iron. The only drawback to the extensive use of aluminium bronze was its cost, about 5s. per lb., but probably before long that would be materially diminished. Very much had been said about the use of scrubbers, and the strength of the ammoniacal liquor produced by the washing of the gas, but it appeared to him that it was wrong to test the efficiency of a scrubber by the strength of the ammoniacal liquor, as with a minimum quantity of water with a maximum quantity of gas passing through the scrubber, a very strong liquor would be the result. The proper way of testing the efficiency of the scrubber was by the purification of gas. The substitution of dilute acids in the scrubber, in the place of water, might have a very good effect in extracting ammoniacal compounds, but unless used with very great care and caution, they would materially injure the illuminating power of the gas produced. The question of public lighting was one of importance, and one upon which many disagreements had taken place between gas companies and Local Boards; yet it was his belief that if those persons who had the control and management of the public lighting could meet the engineers of the gas companies, and discuss the question in a friendly spirit, many of the difficulties and disputes that now arose would very soon be banished. The general mode of supplying gas to public lamps was to give the companies a certain period during which the

Digitized by Google

lamps should burn, and that during that period they should consume a given quantity of gas per hour. Although it seemed a very easy matter to settle the price that should be paid, yet it was a much-vexed question. Those who had the management of public lighting were in constant fear lest the gas companies should not give them the full contract quantity of gas; hence various modes had been introduced to determine the exact quantity of gas consumed, yet several of the modes adopted had been, and still were, subjects of great dispute, as many of the means used were prejudicial to the companies, and were much more likely to create than diminish the cause of the disputes. Take, for instance, the average meter indication. Although gas companies, as a rule, would not object to average meter indication when it was accompanied by proper regulators, yet the modes adopted of compelling gas companies to adopt, under circumstances where they knew they must be the losers, the average meter system, was extremely arbitrary; as, for example, if a meter was placed to an ordinary public lamp, and the tap of that and a neighbouring unmetered lamp were opened to the same extent, the unmetered lamp would consume very much more gas than the metered lamp—for the simple reason that a certain amount of pressure was expended in overcoming the friction of the meter—consequently the gas was discharged in diminished quantity by the burner of the metered lamp.

The double tap had been adopted at Reading and some other places, but it was a no better regulator than the ordinary tap: it would not accommodate itself to the varying pressure during the lighting period, which was one essential for a regulator, for assuming that a metered lamp and an unmetered lamp had been made to consume the same quantity of gas with a given pressure, reduce that pressure, and the uniformity no longer remained, as the consumption would then be greater with the unmetered lamp. To make average meter indication fair to all parties, it was absolutely necessary that each lamp should be so adapted as to consume the same quantity of gas whatsoever the pressure might be; consequently, at all times and under all circumstances, the same amount of light and gas would be given. An instrument that would accomplish that must itself be a good meter. The instrument used was a small governor, which allowed a fixed amount of gas to pass, whatever the pressure. It was used in many towns without the meter, and gave great satisfaction. In the case of Reading, he had heard that the double tap was looked upon favourably, because the amount of gas consumed diminished with the pressure, or, in other words, as the night advanced and the pressure was reduced at the gas-works, so there was a corresponding diminution in the light given by the public lamps. Although at

Digitized by Google

Reading that might be looked upon as an advantage, yet he considered it was the very reverse, as he looked upon public lighting as something more than a convenience; it was a protection for person and property. The early hours of evening were generally well lighted, as the lights of shops and houses added immensely to the illumination of a district, and instead of diminishing the amount of light when the shops and houses were closed, as was the practice at Reading, it was really more essential that it should be increased.

Mr. Cowan explained the action and advantages of Mr. Esson's patent compensating meter, which preserved a uniform water level during the whole time the meter was at work.

Mr. W. Sugg exhibited his photometer drawing, No. 9, which was enclosed in a wooden box, and could be used anywhere. He then stated that Dr. Letheby's photometer was a bar of wood divided upon the same principle as that of the Evans photometer, the difference in the two scales being, that one, or equality, was exactly in the centre of the bar, resulting from the fact that the lights were fixed and the disc was movable. The points of difference between Dr. Letheby's photometer and all others were, that screens were employed of certain dimensions, which were arranged so as to preclude the possibility of reflected light from the walls or ceiling of the dark room in which it was fixed from interfering with the proper action of the instrument, and also that the discs were protected by a sighting box, constructed to move with great ease, without tending to disarrange the lights or pillars upon which the bar rested. The entire arrangement shut out the glare of either of the lights to be compared, and admitted of the nicest appreciation of shadow upon the disc. The same result might therefore be obtained, all other circumstances being alike, from an Evans photometer in any room, and from a Letheby photometer in any dark room.

Mr. Hartley remarked that, in drawing the attention of the meeting to the photometer of the late Mr. Alexander Wright, he had absolutely nothing left to say relative to the principle of its construction, inasmuch as the exposition given by Mr. Sugg equally applied to this as to that of his manufacture. He (Mr. Hartley) must, however, call their attention to the fact that the instrument which was exhibited by him had been for years, and was still, accepted by the bulk of scientific men as the Standard Bunsen Photometer, and that it was more extensively employed by gas companies, corporations, and local authorities, than any other. In efficiency it was not surpassed by any photometer, while it had the advantage of being much less costly than the more elaborate enclosed instruments. It however required to be used in a chamber either painted or draped with black, partially

Digitized by Google

or entirely. If this were inconvenient, the whole apparatus could, for a very small sum, be enclosed with a casing of wood, with doors in front, in a similar manner to photometers which he (Mr. Hartley) had some eight years or so ago fitted up. One was so fitted for St. Martin's Vestry, and used by Mr. Beal.

Mr. STRACHAN said that he came from the chief battle-field of public lighting (Reading), but after fighting for something like two years and a half, he did not think it would be long before the question was settled. One objection of the Local Board of Health to the gas company was the extraordinary amount of money paid for lighting, being about 10s. per lamp; another objection was the quantity of gas consumed. The price of lighting now was somewhere about 11s. The gas company had now nothing to do with the lighting; it was done by a contractor. He stated that several plans were then adopted, but there being such an exceedingly low pressure, the lights were something like candles, but it was allowed to remain during the summer months. They did not say much about it till they were in a position to go to the Board of Health and to say that they were ready to give them a satisfactory light, which was in December—the regular meter system did not commence till the 1st of March, 1864; but previous to that period Mr. Hughes came down from London and commenced with his instruments upon No. 1 lamp at the Town Hall, Reading, and passed along westward. The gas company's pressure was $\frac{7}{10}$ths, and Mr. Hughes set his instruments $\frac{11}{10}$ths of an inch. Of the lamps experimented upon, the lights varied from 1 ft. per hour up to 7 and 8 ft. per hour, although the whole of them were set at the same time at 1.1. After some correspondence, in which Mr. Hughes tried to throw some blame upon him (Mr. Strachan), a tradesman of Reading on behalf of the Board of Health, and he (Mr. Strachan) on behalf of the gas company, went out and took the various meters and made an adjustment, and a fortnight after they were found burning very uniform. Although the double tap regulation had been spoken against, he was certainly in favour of it, because they could set the tap so as to get a very uniform light. Mr. Hughes made some persons believe he was the inventor, but he (Mr. Strachan) was prepared to prove that double taps were in existence twenty years since in Liverpool and other places. It was his opinion that in a very short time meters would be done away with altogether, and a fair equitable adjustment made, seeing they were now burning about 4 ft. an hour, as near as possible. All their experiments were made, after Mr. Hughes was superseded, during the evening with the full pressure on, and at a remote part of the town the pressure was found to be 1 in., 2 in. being the pressure at the works.

Digitized by Google

When the pressure was reduced to $\frac{7}{10}$ths the lights were uniform, those on the highest parts of the town being a little better than those on the lower level.

Mr. Alfred Williams, in closing the discussion, remarked, that the first important point to consider was the number of retorts that could be heated, and the largest quantity of coal that could be carbonised, with the least amount of fuel. Upon this point a great difference of opinion existed, and by looking carefully through the working of the different metropolitan gas companies, it did not appear that those companies, setting more than seven retorts to one furnace, exhibited any evidence of saving in fuel; and, from his experience, he was persuaded that seven retorts to one furnace, if properly set and carefully fired, with a furnace of small dimensions, with the heat properly carried through the setting, and the arch and brickwork above well built to prevent loss of heat through radiation, was as economical, as setting a larger number in a bed; he thought that seven retorts were also more easily worked, for if a larger number were set, some would be too high for the men to draw and charge quickly. Another point that had not been mentioned was, that, in drawing the retorts, it was advisable to do so quickly, so as to get them charged and closed up to prevent as much as possible the cooling of the whole bench. Now this would affect a bed of, say, eleven retorts, more than it would seven, as it would take longer to draw and charge them. He regretted that more discussion had not taken place upon the mode of setting the retorts, as there were a number of different plans adopted by the engineers of the various gas companies; he preferred the mode adopted at the Phœnix, Commercial, Crystal Palace District Gas Companies, &c., to any other, and which was advocated by the author of the paper (Drawing No. 1), as it afforded good and substantial protection to the retorts. Retorts set on this plan he had known worked for above four years. The use of iron retorts had now almost ceased, except for small works; and, even in small works, he was of opinion that, if carefully looked after and attended by competent workmen, clay retorts would take the place of iron, with very considerable advantage and saving to the companies. He was aware of several instances where they had given good dividends to the shareholders, where none, or very small, had previously been paid. The average life of an iron retort could not be taken at more than ten months, whereas clay would last three to four years; and clay retorts did not cost so much in setting as the iron, thus being a saving in cost at first. The only reason for clay retorts not answering in small works was, that the men employed were not properly instructed,

Digitized by Google

or were obstinate, and preferred keeping to their old ideas to admitting anything new, imagining the new might give them more work and trouble. He considered that an exhauster would be beneficial in all works where the make of gas was from 25,000 to 30,000 per day.

The best shape for a retort, he considered, was that which would give the best and largest area for the coals, and that afforded the easiest shape for the withdrawal of the coke and the charging with coal; there could be little doubt that the circular retort was the strongest form, and, if used of sufficient size—say 15, 16, 18 inches—the best that could be adopted; the oval was good, as it gave good surface for the coal; the D shape was not so good, as it was not all of an uniform thickness, and therefore did not contract and expand equally.

The deposit of carbon that took place on the retorts should be carefully watched, and cleared off as soon as possible, as the longer it was allowed to remain the more difficult it was to remove. The plan mentioned by the author for removing the carbon was the one usually adopted, although it would be very desirable, if possible, to find some other means, as allowing the lid of the retort to be opened, either partially or wholly, for the admission of the air, necessarily tended to lower the heat in the whole bench. The form of condenser used mattered very little, so long as the surface was sufficient to cool the gas to a proper limit and cause the deposit of the tar, &c. He preferred the annular condenser, as it gave a great surface, occupied little room, and could be erected as cheaply as any other form.

The purification of the gas was a point of very great importance, and, with the use of the oxide of iron and Mr. Mann's excellent scrubber, and a little lime to take up the carbonic acid, he thought all the impurities should be extracted and enable the companies to supply pure gas. The various forms of exhausters had been discussed, but he certainly preferred Mr. Beal's, as it was very simple, occupied very little room, made scarcely any noise, and was as cheap as any. Mr. Jones's exhauster he had used, but objected to it in consequence of the noise made by it. Mr. Anderson's he had also seen, but he did not like the principle so well as Beal's; but where it was in use he had heard that it worked well and effectively, and gave great satisfaction. The exhauster spoken of by Mr. Paddon he did not think so effective as the rotatory exhâuster, and it was more costly, and occupied more room.

The question of gas-holders was a most important one, as it formed one of the largest items in the cost of gas apparatus. It was necessary to have, if possible, the full storage room for the largest quantity of gas required in any one day. Sufficient gas-

Digitized by Google

holder room was important, as it enabled the gas engineer to work on the most economical principle; a deficiency of gas-holder room often obliged the engineer to have extra beds of retorts ready heated, to be charged on any sudden emergency, especially in London, where heavy fogs occurred, and when almost as much gas was required in the daytime as at night, which necessarily added to the expenses, in an undue ratio, to the regular working of the company.

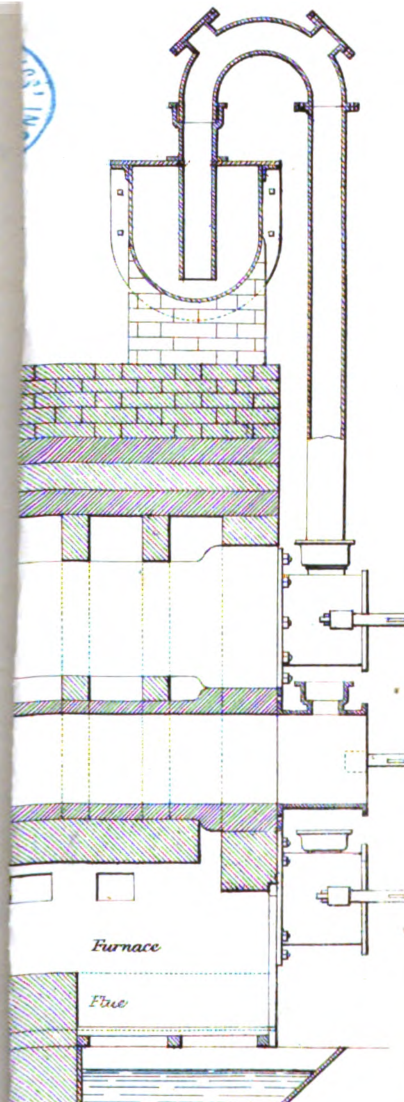
The form of gas-holder now universally adopted was circular, as single lift or telescopic vessels, and, in some cases, three lifts. There could be little doubt that the single lift was the most simple and the best, as it was the least complicated, but double lift or telescopic gas-holders were safe if properly constructed, and they had a great advantage over single-lift holders, as nearly double the amount of storage could be provided on the same space of ground at the same cost as regarded the tank, and about one-half extra cost of the holder for the outside vessel and the extra height required in the guide columns. And it was advisable, also, to have the gas-holders as large as possible in diameter, as a large holder would be very much cheaper than several small holders capable of holding the same quantity of gas, and ground space, at all times valuable, would be economised.

The materials used for the tanks of gas-holders depended upon the nature of the ground. It was usual to build them of brick, with the back of the brickwork carefully puddled, and it was necessary also, to make a good and perfect tank, to puddle over the bottom of the tank also. In marshy or sandy ground it was advisable to make the tanks of cast-iron or wrought-iron plates.

The construction of gas-holders was fully explained by the author, who mentioned, among others, the large holder of the Phœnix Gas Company at Kennington, of which he (Mr. Williams) had the superintendence of the construction and erection. That holder was a double lift, and without any trussing in the crown, as explained by the author; and that principle was correct, as when once the gas-holder was at work the trussing was scarcely ever required for bearing the top plates, and he considered that the metal used for constructing the trussing could be more advantageously used in the plates of the vessel itself, making it more durable, the top curb being made sufficiently strong to keep the holder in a perfectly cylindrical shape. The author stated that wrought-iron columns were adopted in that case instead of cast-iron; that innovation was a saving of about 30*l.* per column, and there being sixteen columns, the saving was 480*l.* The tie-rods used instead of girders in that holder he did not think were so useful as girders would have been, as, when the

Digitized by Google

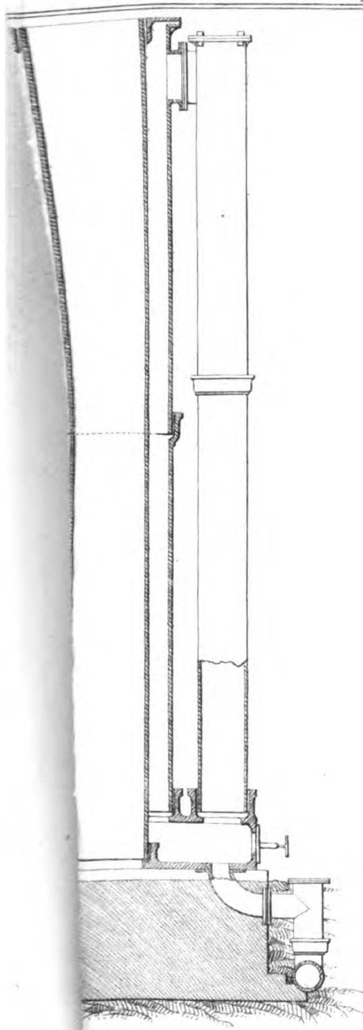
PLATE 1



Newbery & Alexander, Lith.
43, Castle Street, Holborn

Digitized by Google

Digitized by Google



...et = 1 Inch.

Newbery & Alexander Lith.
45, Castle Street, Holborn

Digitized by Google

CALIFORNIA

Digitized by Google

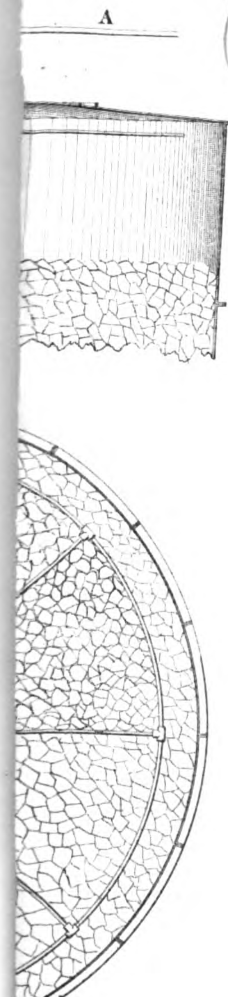
Digitized by Google

Digitized by Google

Digitized by Google

ATER DISTRIBUTOR.

SAN FRANCISCO MECHANICS' INSTITUTE.



Newbery & Alexander, Lith.
43, Castle Street, Holborn

Digitized by Google

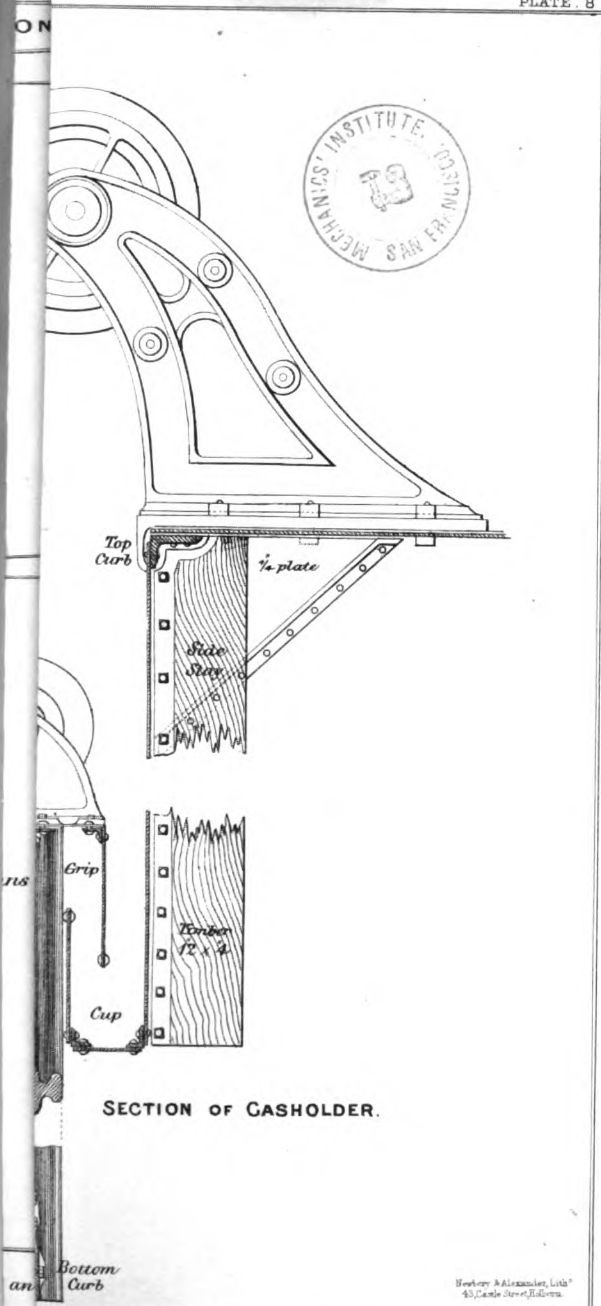
Digitized by Google

Digitized by Google

INSTITUTE.

Digitized by Google

Digitized by Google



SECTION OF GASHOLDER.

Newbery & Alexander, Lith.
43, Castle Street, Holborn.

MECHANICS' INSTITUTE, SAN FRANCISCO.

Digitized by Google

Digitized by Google

Digitized by Google

Sectional Drawings (Plate 9, Fig. 1) of Station Gas Governors, as manufactured by the firm of A. Wright, 55 and 55a, Millbank Street, Westminster, for regulating the pressure of the Gas from the Works into the Street Mains. In each case it will be seen that the instrument consists of a water tank, with concentric pipes having horizontal inlets and outlets, and a gasholder to which a cone (technically so called) is suspended so as to work centrally through a plate on the top of the centre vertical pipe, forming a valve capable of contracting or enlarging its aperture as the gasholder rises or falls. The cone and plate are both truly turned, and are constructed generally of cast iron. The gas on entering the inlet passes up the centre pipe through the valve and escapes through the outlet. If the discharge of gas from the outlet mains be less than the quantity which is capable of passing through the valve under the acting inlet pressure, the gasholder rises, thereby lifting the valve and diminishing the valve opening to the extent necessary to balance the supply and discharge. It thus maintains equality of pressure under very considerable variations of discharge.

The Governor shown in Fig. 2 is constructed with a float in its gasholder which exactly sustains in equilibrium the gasholder with its cone when immersed in the water-tank. Pressure is obtained by placing flat curved weights upon a circular plate on the top of the gasholder. With Fig. 7 the gasholder is counterpoised by circular weights, and the pressure is obtained by removing as many as may be needful. These weights are proportionate to the areas of the gasholders, and cause them to give pressures ranging from 0·1 to 3 or 4 inches head of water.

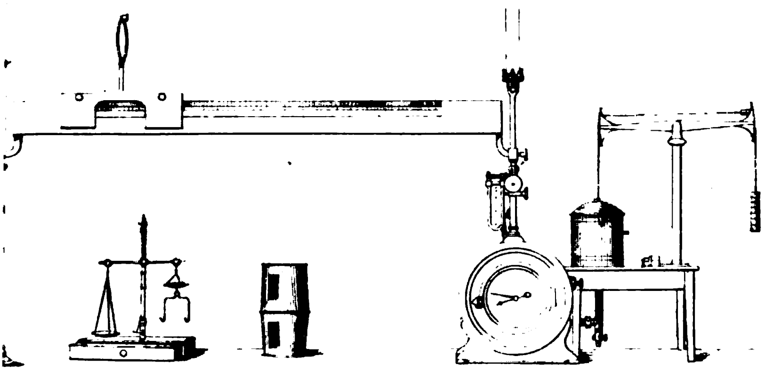
All the parts of these Governors are constructed of cast iron, with the exception of the gasholders, which are of stout tinned charcoal sheet, and the scales and fittings, which are of brass.

It is to be remarked that the cones (so called) in these instruments are of a parabolic form, and by this means they diminish the valve openings in equal proportion for each inch in length from the apex to the base.

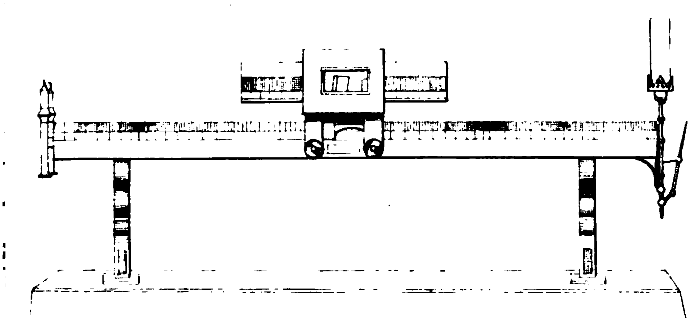
An Exhauster Governor or Regulator is shown on Plate 3. It is a simple gasholder and tank in connexion, as shown, with a throttle valve, the latter being fitted into a comparatively small main passing between the inlet and outlet of the Exhauster. From the side nearest the inlet of the Exhauster a pipe is carried from the small main into the gasholder of the Regulator. Finally an adjustment is made by the addition of counterpoise weights, so that the gasholder is sustained at its highest working point and the throttle valve closed when the Exhauster is working at such a speed as to produce equilibrium of pressure, or any required exhausting power. Should this speed be exceeded, the gas is abstracted from the gasholder, which immediately descends, opens the throttle valve, and thereby allows a portion of the gas to pass from the outlet to the inlet of the Exhauster, and thus prevents the required conditions of working being violated.

Digitized by Google

WRIGHT'S PHOTOMETER.



SUGG'S PHOTOMETER.



N Spon, 16 Bucklersbury, London.

Digitized by Google

Digitized by Google

METER.

Fig. 2.

INSTITUTE BOSTON

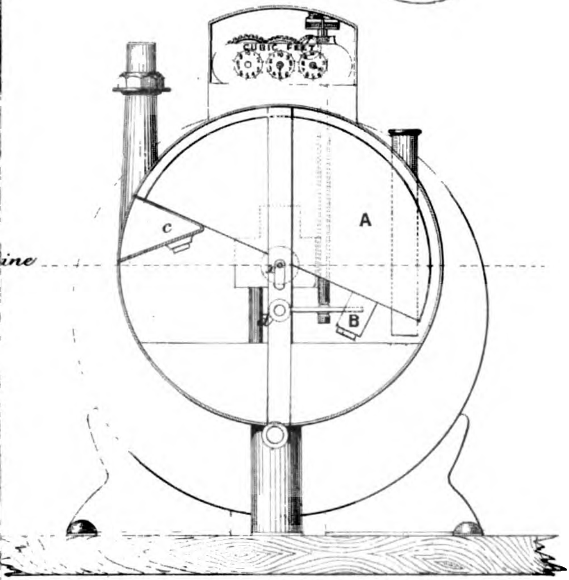


Fig. 4. *A horizontal view of meter with top lifted.*

Float A is a hollow half cylinder which rotates upon its own axis (x), and is made half the specific gravity of water, so that when water is poured into the meter, being confined by its own axis, it rotates around it in the direction of the arrow until it comes to rest upon the inlet box (c): the water in the meter then rising above the level of the spout (d) overflows at plug (e) showing that the meter is properly charged.

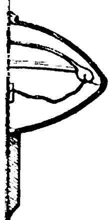
Newbery & Alexander Lith.
43 Castle Street H...

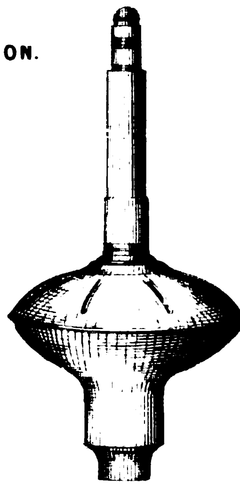
Digitized by Google

Digitized by Google

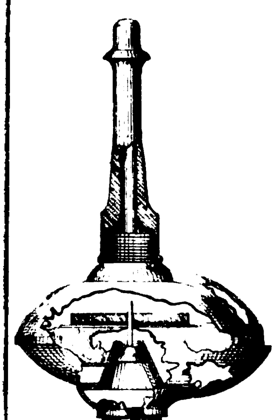
ULATORS FOR STREET LAMPS.

J. B. PADDON.





W. SUGG.



& F. N Spon 16 . Bucklersbury. London.

Digitized by Google

Digitized by Google

holder was down the ties were of no use to prevent the columns bending inwards, which they were liable to do from strong winds: they being 73 ft. high; of course when the holder was fully up, or partially so, the holder prevented the inward thrust, and the tie-rods then came into action. He might here state that the following were the total weights in the holder: cast-iron in caps and bases of columns, guide-rods, &c., 92 tons 14 cwt.; cast-iron in holder, 50 tons 6 cwt.; total cast-iron, 143 tons. Wrought iron in columns, tie-rods, &c., 84 tons 6 cwt.; wrought-iron in holder, 207 tons 14 cwt.; total wrought-iron, 292 tons; total cast and wrought-iron 435 tons. That holder was a very cheap one, costing only about 11*l.* 2s. per 1000 ft. of holding capacity, whereas some gas-holders had cost as much as 30*l.*, and even 40*l.* per 1000 ft.

The governor was absolutely required in all gas-works for the proper and economical regulation of the pressure of the gas supplied to the mains. The action of that vessel, and also wet and dry meters, was thoroughly explained by the author of the paper, and also by some of the speakers during the discussion. There was, no doubt, something to be said in favour of both wet and dry meters, but he was of opinion that meters were not yet brought to perfection, and thought a metal was yet to be found that would withstand thoroughly the action of the gas upon it; when that point was arrived at, meters would be rendered much more durable. The distributing mains should be well laid, and care should be taken that the pipes were of a proper size, so as to afford a good supply, and decrease as much as possible the leakage of the gas.

With respect to the charging for public lights, which had been so ventilated during the discussion, he was of opinion that it was not fair to the gas company to have meters fixed on a few lamps, and to be paid by the average quantity registered at those meters for the whole of the lamps; but if meters were used, they should be fixed to all lamps, or a series of lamps attached to one meter, and each series supplied by an independent service-pipe. He did not agree with the use of the double taps, as he could not see how they could regulate themselves to the continued alteration of pressure that took place, but thought that a governor (Plate No. 10) should be fixed to each lamp, which, if properly constructed, ought to so regulate the pressure as to give an uniform light at all hours.

Digitized by Google

April 4*th*, 1864.

C. L. LIGHT, Esq., in the Chair.

ON THE USE OF THE CORNISH PUMPING ENGINE.

By A. Fraser.

From the earliest period of the world's history the raising of water from a low to a higher level, by some mechanical contrivance for the saving of labour, has exercised the ingenuity of mankind; and the works of irrigation carried out from time immemorial in China and other parts of the East, have brought into use many very ingenious machines. But the application of steam for this purpose, it need hardly be said, has thrown their performance into the shade, and they are now considered little better than toys. It is a remarkable fact that the men who were the first to perceive the wonderful advantages that would accrue from the use of steam, appear to have first turned their attention to the raising of water by its means, and the earliest forms of steam engines were pumping engines. As early as the year 1663, the Marquis of Worcester, in his "Century of Inventions," describes what he calls a "Fire Water Work," which is evidently the most simple form of single-acting engine, in which the pressure of the steam was applied directly to the water, without the intervention of piston, cylinder, or pump-work. The marquis appears to have obtained an Act of Parliament, or patent, for the protection of his invention, under the name of a Water Commanding Engine; but as the duty performed by it was only the 200th part of that of a steam engine of the present day, it probably did not come into very general use. But to the Marquis of Worcester must be ascribed the first invention and trial of a practical mode of applying steam as a prime mover, and of applying it to one of those great purposes for which it has been so useful to society.

Several other early inventors and improvers of the steam engine appear to have considered it exclusively as a means of

Digitized by Google

raising water, as Sir Samuel Morland, in 1683, Dr. Papin, in 1695, Thomas Savery, in 1698—who published a description of his invention in a pamphlet called the "Miners' Friend," and exhibited a model of it before the Royal Society in 1699. Several engines for raising water appear to have been erected on Savery's plan, and to have succeeded tolerably well where the lift was not more than 40ft., but as the principle consisted of a vessel alternately filled with steam and cooled by a jet of cold water, the effect produced was very small compared with the fuel consumed.

But the immense expense incurred in raising water from mines so embarrassed their proprietors, that most powerful incentives existed at that period to engage further researches on the subject, and to this stimulus we are indebted for another construction of the steam engine by Thomas Newcomen, a smith of Dartmouth, who took out a patent in 1705 for a form of engine which was, in fact, the rudiment and first conception of the present single-acting engine. It consisted of a piston in a cylinder, the top of which was open to the atmosphere, steam being admitted under the piston to force it to the top of the cylinder. Cold water was next introduced, which cooled the cylinder and condensed the steam, causing a vacuum, the pressure of the atmosphere bringing the piston to the bottom of the cylinder.

It was while attending one of Newcomen's engines that the boy, Humphrey Potter, who preferred playing with his companions to the monotonous labour of opening and shutting the various cocks, contrived, by attaching strings and catches to the working beam, to make the engine self-acting, after which more permanent arrangements were made for this purpose.

In 1775, John Smeaton designed a pumping engine, the cylinder of which was 72 in. in diameter, and the stroke 9 ft., and introduced several improvements, but so imperfect was the state of mechanical science in his day, that he actually designed an engine to be erected at Long Benton to raise water for turning a water-wheel to draw coals from a pit.

Hitherto the only form in which the pumping engine had been employed was the atmospheric, with an open-topped cylinder, and it was not till 1780 that James Watt, by his striking improvements, brought the machine to something like perfection, and caused its introduction to any extent. He provided the cylinder with a cover, contrived the separate condenser and air pump, and worked the steam expansively to a certain extent. This principle was adopted in an engine erected by Watt at the Shadwell Waterworks. In 1781, Jonathan Hornblower patented a double cylinder engine, in which the steam was used in a small

Digitized by Google

cylinder at a high pressure, and expanded in a large cylinder. This is a form of engine in very extensive use at the present day; but the greater amount of surface, causing friction and condensation, diminished to a great extent the apparent advantages of this mode of working, and induced a preference for the single cylinder engine, with its greater simplicity and freedom from complication. It may be observed that the first form of double-beat valve was introduced by Hornblower.

In 1802, Messrs. Trevithick and Vivian began to make use of steam at a high pressure; and, in 1804, on the expiration of Hornblower's patent, Arthur Woolf improved upon his ideas, and produced the well-known Woolf's engine, with two cylinders for using high-pressure steam expansively. With these engines a duty of fifty million pounds raised 1 ft. high by the consumption of 1 cwt. of fuel, was obtained. After this Samuel Grose, a pupil of Mr. Woolf, turned his attention to the improvement of the steam valves, and by a proper arrangement of their areas obtained a duty of eighty-four millions, with an engine erected at Wheal Towan Mine, in Cornwall, as reported by Messrs. Lean. In this engine only one cylinder was employed.

After this time Woolf's engines appear to have gone out of use; and the next alteration in the form of the engine was made by Mr. Sims, of Redruth, who patented a combined engine with the small cylinder placed over the large one; but as the space between the two pistons was always exposed to the temperature of the condenser, great loss of heat was the result, and, at the present time, most of these engines that were made have been abandoned.

The constantly increasing demand for engine power for raising water renders the question of the description of engine to be employed one of the greatest importance; and there are many circumstances to be taken into consideration in determining whether to make use of a rotary or reciprocating engine.

In some cases it may be desirable to economise the first outlay rather than the future working expenses, and in others there may be sufficient capital available to warrant the employment of machinery which, though costly in the first instance, may enable the owners to carry out their operations at the lowest possible expense for years to come, without any material repairs or alterations.

Double-acting rotating engines may be classed under the first head, and single-acting Cornish engines under the second. The advocates for double-acting engines, working a fly-wheel, are in the habit of ascribing to them, in addition to their original low cost in comparison with Cornish engines, several advantages —as economy in fuel, safety in working, and a freedom from

Digitized by Google

breakage in the mains and pipes, in consequence of the flow of water being maintained in a constant stream, instead of being propelled by strokes or jerks; and asserting that the single-acting engine labours under the disadvantages of a fixed load to lift at all times, although the height to which the water is to be raised constantly varies; a propensity to burst the pipes connected with it from the intermittent nature of its action; a danger of breakage to its own parts, from the use of high-pressure steam on the one hand, and the heavy weight to be lifted on the other; and increased cost of attendance, from the extreme care and vigilance required for the avoidance of accidents. It remains to be seen how these assertions are borne out by facts.

The introduction of the single-acting Cornish engine in its present form, for pumping purposes, to London, dates from the year 1837, when Mr. Wicksteed purchased an 80-in. cylinder engine in Cornwall, made by Harvey and Co., and re-erected it at the East London Waterworks, where it is working at the present time. But it is well known to have been used for many years in the county of Cornwall for pumping water out of mines, the arrangement being as follows: The engine is fixed so that the outer end of the beam hangs over the shaft of the mine, and is attached to the pump-rods. These pump-rods, being of enormous weight, are lifted by the engine, and the pumps being at various distances down the shaft, the weight of the rods descending forces the water up a rising pipe to the surface. The duty performed by these engines has been stated at from one hundred to one hundred and ten millions of pounds weight lifted one foot high with 1 cwt. of coal; but from the pump-work being, in most cases, so far underground, there is no doubt that facilities were given in many instances for letting in air into the pumps, and so arriving at a fallacious result. This large duty has, however, of late years been much reduced, and various causes have been assigned for this apparent falling off—such as the greater depth now attained in mining operations, the modern practice of sinking shafts at an angle instead of perpendicular, so causing increased friction, the diminishing interest felt in the subject by the owners of mines, &c.; but the most probable cause for the seeming reduction in the rate of duty is the use of inferior coal, which is found to be more economical in proportion than fuel of the best quality, of course where the boilers and grate surface are adapted for the purpose of slow combustion. This fact has been proved by experiment at the waterworks at Kew Bridge, where a 90-in. cylinder Cornish engine was lately worked for several days from five boilers, burning the best coal that could be procured, costing about 25s. per ton, when the duty performed was ascertained to be one hundred and five millions; the average

Digitized by Google

duty with small coal, costing 10s. 9d. per ton (which is the fuel in ordinary use), being sixty-two to sixty-five millions.

Setting aside the Cornish engine as employed in mining operations, and confining our remarks to the engine as used for the purpose of supplying water to towns and cities, it may be as well to limit our attention to the Cornish engine as we find it employed in the various establishments of the London water companies, where operations are conducted on the most extensive scale, and everything has been done to bring the pumping engine to perfection.

The London water companies have a very large capital embarked, and having a constantly increasing quantity of water to raise—in some cases three or four times over—it has become with them a very serious consideration to secure a description of engine that will lift the greatest quantity of water with the smallest consumption of fuel and the smallest number of attendants, and will, in addition to this, meet the increasing demand for water without alterations or additions, or much increased working expenses. All these conditions are fulfilled in the Cornish engine to a greater extent than in the rotary engine.

The thorough-bred Cornish engine comprises a cylinder very strongly bolted down to a massive stone or granite loading, the piston rod being attached by the usual parallel motion to the inner end of the beam, to the outer end of which the pump-work is fixed in a similar manner. The cylinder is invariably surrounded by a cast-iron jacket, into which steam is introduced from the boilers at the top, a drain pipe being provided at the bottom to take the condensed water into the boilers again. By this arrangement the temperature of the steam is kept up at the moment of its introduction into the cylinder to the same point as in the boilers, and this is so important as far to exceed the small loss of heat occasioned by the condensation of the steam in the jacket, which becomes in fact a super-heater. The stuffing-box of the piston-rod contains a lantern brass, a contrivance by which steam is introduced from the boilers by a pipe into the middle of the packing, so that it is impossible for air to be drawn into the cylinder in the event of the packing of the piston-rod leaking. There are four valves in connexion with the cylinder, all of which are on the double-beat principle, and are made of gun metal. The first valve is on the steam-pipe, and is worked by hand. This is called the governor, and regulates the quantity of steam to be admitted to the cylinder. The second is the top steam valve. This is worked by the engine, and is opened by the operation of a cataract, the adjustment of which is under the control of the engineer, and is shut by a slide fixed to the plug-rod, the slide, being movable, regulating the point of the stroke

Digitized by Google

at which the steam is cut off. The third is the exhaust valve, also worked by the engine, and also under the control of a cataract. The fourth is the equilibrium valve, which is kept closed during the working stroke, and is opened by the engine during the up stroke. The air-pump, condensers, &c., are of the same description as those in use in ordinary engines, but care is taken to have all the pipes and valves in connexion with them as large as practicable. The beam, which is generally of cast iron, and of great strength and weight, is supported by a massive wall, and a great improvement has been lately introduced, by forming the beam of wrought-iron plates; but a very strong beam is frequently made by trussing the cast-iron beams with strong iron tie-rods. The pump-work usually consists of a plunger, which is loaded to a weight sufficient to counterbalance the height of the column of water to be raised. The pump-valves are usually on the double-beat principle, and as the plunger is raised very quickly, and the water should follow through the bottom valve with great speed, the bottom or suction valve is usually made of larger area in its apertures than the top or delivery valve, through which the water is propelled more slowly, and a very decided improvement has taken place in the working of several engines by the introduction of a four-beat valve, patented by Mr. Husband.

But the most important point to be attended to is that the level of the water in the reservoir or pump-well should always be at least as high as the level of the top of the suction valve, and in arranging the relative levels of the water to be pumped and the valves of the pump, it will always be found more convenient to force the water from the lowest possible point, and not to have to draw it up to the plunger case any higher than is positively necessary. It is usual to provide a perpendicular stand-pipe, up which the water is forced to fall over into the main pipes at any point that may be determined. The great advantage of the stand-pipe is its safety, as in case of a breakage occurring in the main-pipes, the column of water left in the stand-pipe prevents the loaded plunger from falling with any very great force; but to provide against any such contingency, as well as to limit the length of the strokes, wrought-iron spring beams and catch-pins on the engine beam are usually provided.

Between the pump-work and the stand-pipe a cast-iron air vessel is attached, placed in a vertical position on the outlet pipe; the air which collects in the upper part of the vessel forming an elastic cushion, takes off a considerable portion of the shock at the commencement of the descent of the plunger. There is a small air pump worked by the engine which keeps up a supply of air to the air vessel, as it is found that under great pressure

Digitized by Google

the air becomes mixed with the water and carried away into the stand-pipe. Some of the London pumping engines have double-acting pumps, in which the outer stroke is performed by a loaded plunger, and the in-door stroke by a piston; the different areas being arranged to suit the height of the lift. With these pumps it is usual to work with an air vessel of considerable size, and to dispense with the stand-pipe altogether, substituting for it a balance safety plunger, the invention of Mr. Husband, of Hayle. The economy in working is less than the single-acting pump, in consequence of the steam being kept on the piston a longer time, and the difficulty of carrying out the principle of expansion so far as in the former case.

The whole of the steam pipes, and the cylinder, jacket, nozzles, &c., are carefully covered up with felt, and cased in wood.

The boilers are usually on the single-tube principle, and should have a capacious steam chest, from which the steam pipe is taken to the cylinder, and the larger these pipes and all the passages in connexion with them are, the better.

The boilers are carefully built in with fire bricks, and covered with dry sand, and so small an amount of heat is allowed to escape, that during the recent frost ice might be seen on the stoke-hole floor of the boiler-house in one of the London establishments. It may be observed that experience in boilers shows that the greater the number of boilers in use, the greater the economy in fuel and in wear and tear; and it is advisable to have as many spare boilers as possible, in order that plenty of time may be allowed for them to cool down before cleansing. Nothing ruins boilers so much as the rapid change of temperature, and consequent contraction, through letting in cold water before they are quite cool.

As every double stroke of the engine comprises in itself all the operations of the machine in a complete form, and no acquired momentum is carried on to the next stroke, a description of its action during one stroke is sufficient.

The steam in the boilers being at a pressure of from 35 lb. to 40 lb. per square inch above the atmosphere, the stroke commences by the sudden opening of the exhaust valve, which ensures a thorough clearance of the cylinder under the piston; the steam valve is then thrown open by a heavy weight suddenly disengaged by a catch connected with the cataract; the steam rushes from the boilers with its full pressure into the cylinder, and forces down the piston; the steam valve is then closed by a slide on the plug-rod which is adjusted so as to close the valve when the piston arrives at $\frac{1}{3}$ to $\frac{1}{4}$ of the stroke. The remainder of the stroke is accomplished by the expansion of the steam left in the cylinders, which is reduced to a pressure below that of the

Digitized by Google

atmosphere by the time the piston has reached the bottom of the cylinder; at this point the exhaust valve is closed and the equilibrium valve is opened, which establishes a connexion between the top and bottom of the cylinder; the weight of the loaded plunger then raises the piston to the top of the cylinder, forcing the steam from the upper to the lower part of it; the equilibrium valve is closed shortly before the finish of the stroke, so that a portion of steam remains above the piston, and becomes compressed, keeping the space over the piston full of steam, and at a high temperature ready for the next admission of steam.

In a pumping engine constructed on this principle, and of the best materials and workmanship, a greater amount of working effect is obtained from a given quantity of fuel than in any machine known at the present time; and this is, to a great extent, the result of the great attention paid to the prevention of loss of heat from radiation, and the plan of using the steam at a high pressure, and letting it into the cylinder in such exceedingly small spaces of time. The steam is maintained at a high pressure without difficulty, where a sufficient number of boilers is provided, and the loss of steam at each stroke is hardly perceptible, and in consequence of the slow rate of combustion maintained in the furnaces, an opportunity is afforded of burning the cheapest description of fuel. The coal in use at the pumping stations in London, where Cornish engines are employed, is so small as to be little better than dust, and costs from 10s. to 11s. per ton delivered. The number of boilers and area of fire grates is arranged so that the consumption is at the rate of about 4 lb. of coal for every square foot of fire grate per hour: but in the recently constructed works of the Grand Junction Company, at Campden-hill, the rate of consumption is only 1¼ lb. per square foot per hour.

It may be observed that experience in the use of Cornish pumping engines during the last twenty years, points to the conclusion that the larger the engine the greater the economy in working, the friction being less in proportion both in the working parts and in the steam passages, and the number of men required to attend to a large engine is no greater than for a smaller one. The engines that do the best duty have cylinders 80 in., 90 in., or 112 in. in diameter. The engine at Great Wheal Vor and that at Lea Bridge are 100 in. in diameter.

The single-acting Cornish engine is peculiarly adapted for the purpose of a waterworks in which the quantity of water to be raised varies or increases from time to time. From the nature of its action, the piston travels at the same speed, whether working at the rate of one stroke per minute or twelve strokes, and consequently the proportion of steam used to water raised

Digitized by Google

remains the same in both cases; whereas, while a crank engine is working slowly, and raising but a small quantity of water, a large quantity of steam is consumed in bringing the piston to the end of its stroke, and the objection often made to the principle of employing the engine to raise a weight which remains always the same, while the levels to be reached by the water vary from time to time during the day (as must be the case in the districts of all London water companies), does not in reality apply to Cornish engines in particular. It is a disadvantage under which every description of engine must labour, and it does not appear to have been overcome in those works using crank engines, viz. the Chelsea works, the New River, and the Lambeth works, in all of which high-level reservoirs are provided of sufficient altitude to supply the highest tenant in the district, and to this maximum height the whole of the water is raised, whereas the majority of the houses supplied from the same reservoir do not require perhaps half such a pressure.

It has frequently been mentioned that the single-acting Cornish engine is dangerous, that it is liable to accidents in its own parts, and by the intermittent nature of its action, bursts the pipes in connexion with it more frequently than crank engines; in fact, that the only safety consists in the fly-wheel. But the fact is, that each stroke of the Cornish engine being, as before stated, a perfect and complete operation, the pause which takes place at the end of it brings everything to a state of rest, and should any such accident occur, the engine simply stops; but in the rotary engine, the heavy fly-wheel spinning round with an accumulated momentum, drives the water with irresistible force along the mains, and should any of them be shut down, it must inevitably burst the pipes or break the engine, and in case of accident, is by no means easily stopped in its career; and in practice it is found that, if a proper stand-pipe is provided, accidents of this nature are very rare with the Cornish engines.

With respect to the cost of attendance on these engines, or, in other words, the wages of engine-drivers, certainly the minimum of expense in this respect has been reached in those establishments where Cornish engines are employed. The machines are so self-acting, and it may almost be said intelligent, that one man only is required to attend to an engine of the largest size; and a Cornish engine, with a cylinder nearly 10 ft. in diameter, may be seen at work in one of the London waterworks under the control of one man, whose wages are probably not more than 2*l.* per week. In another establishment, containing two engines of about 150-horse power each—one of which works night and day, and raises three thousand millions of gallons of water, equal to

Digitized by Google

1½ miles square, and 9 ft. deep, 60 ft. high in the course of the year—the cost of engine-drivers, stokers, coal wheeler and boiler cleaner, superintending engineman, &c., is only £550 per annum; and these men not only work the engines, but keep them packed and in repair, and clean the boilers and flues, being at the rate of 22,000 gallons for a penny.

There is no question that the first cost of Cornish engines is considerably in excess of rotary engines, from the expensive description of foundations that is indispensable. Probably the cost of an engine of this description, with pump-work, stand-pipe, and air vessel, with boilers, houses, &c., would approach 100*l.* per effective horse power; but the expense has been much reduced in some direct-acting engines lately introduced, in which the cylinder is placed vertically over the pump, and the beam is dispensed with. This arrangement reduces the cost of the building by one-half, and this engine is much lighter and more handy than the beam engines; and the absence of beam and parallel motion reduces the chance of accident very materially, and a greater speed in working is attained, consistently with safety, than with the beam engine.

To show the durability of Cornish engines, it may be stated that there are engines now working in London that have been at work for the last thirty years; and many of the engines at the London waterworks have worked night and day for twenty years, without any material repairs, further than the renewal of packing to piston, &c. But at the end of that time a thorough overhaul is required, and it will probably be found that the high-pressure steam has eaten the cylinder cover and nozzles, and other portions of cast-iron not subject to friction but exposed to the first rush of steam, into holes. These being renewed, and fresh brasses put in the bearings, the engine is as good as new.

At the Ipswich waterworks a trial was recently made to ascertain the comparative duties performed by a Cornish engine and a crank engine, working under precisely similar conditions, and in fact, from the same boilers. The Cornish engine has a cylinder 33 in. in diameter, and 8 ft. stroke, single-acting. The crank engine has two cylinders, one 17 in. diameter and 3 ft. 6½ in. stroke, and the other 29 in. diameter and 5 ft. stroke, working a double-acting pump.

The result was a duty in the case of the Cornish engine of seventy-six millions, and the crank engine fifty-four millions; and it is the practice in these works to do all the work with the Cornish engine, and keep the crank engine in reserve.

There are eight water companies supplying the metropolis with water, pumping daily at least 100 millions of gallons, and a

Digitized by Google

considerable portion of the quantity is pumped two or three times over. This involves the daily labour of lifting the contents of a reservoir, a quarter of a mile square and 10 ft. deep, as high as the London Monument; and for this purpose five of the most important companies use exclusively Cornish engines; so that, in round numbers, three-fourths of the water supply of this metropolis is carried out by the adoption of the Cornish principle—a convincing proof that, in the opinion of hydraulic engineers, there are advantages to be derived from its application to this purpose.

The advocates for the adoption of the Cornish engine for pumping purposes, maintain that the unquestionable advantages of high speed of piston, slow combustion of fuel, and great expansion of high-pressure steam, are to be found in this machine to a greater extent than in any other in existence; and they confidently hope, by increasing the size of cylinder and length of stroke, with a higher speed of piston and a greater expansion of steam in working, to obtain a still greater effect from a given quantity of fuel than has ever been arrived at hitherto.

For drainage purposes, engines on the Cornish principle have been extensively introduced in England, Holland, and elsewhere; and it is rather surprising that, in designing the various works for the drainage of London, the economy which experience shows is attendant on the pumping of water by these engines, appears to have been overlooked.

One of the most successful examples of the use of the single-acting Cornish engine for drainage purposes is the drainage of the Lake of Haarlem, in Holland, which covers a space equal to 45,230 acres to an average depth of 14 ft., the cubic contents being 800 millions of tons of water—a quantity sufficient for the supply of London for seven years. This has been pumped out into the sea by three engines, which will hereafter have to be worked occasionally, as the rain-fall alone amounts to thirty-six millions of tons monthly, and must all be removed artificially. These engines are all of the largest description, and demonstrate the advantage of employing machinery of this sort on the largest possible scale. An account of one of them will, perhaps, be interesting.

The engine-house is circular, and stands in the centre of a reservoir containing eleven pumps; the suctions communicating with the lake, and the heads brought up through a flooring forming the bottom of a trough running into the sea, 13 ft. above the bottom of the lake.

The engine has two cylinders, one within the other, fixed concentrically, united at the bottom, but with a clear space of 1½ in. between them at the top under the cover, which is common to

Digitized by Google

both. The large cylinder is 12 ft., and the small one 7 ft. in diameter. The small cylinder is fitted with a piston, and the space between the cylinders with an annular piston. The pistons are connected, the inner by one piston-rod, and the outer by four smaller rods, to a large cap or cross-head, having a circular body 9 ft. 6 in. in diameter, and formed to receive the ends of the balance beams of the pumps.

The pumps are eleven in number, and each 63 in. diameter, with 10 ft. stroke, with a cast-iron balance beam turning upon a centre in the engine-house wall, and having one end connected with the cap of the engine, and the other with the pump-rod. Each pump-rod is of wrought-iron, 3 in. diameter, and 16 ft. long, with an additional length of 14 ft. of chain attached to the pump piston. Each pump is calculated to lift six tons of water per stroke, and the total quantity actually delivered by the eleven pumps is sixty-three tons. The action of the engine is as follows: Steam being admitted, the pistons and heavy cap are thereby raised, and the pump pistons make their down stroke; at the top of the steam stroke a slight pause is made to enable all the valves to fall out and be quite ready to take their load on the down stroke without shock. In order to sustain this great weight during this interval, an ingenious hydraulic apparatus is brought into use, in which the weight is supported by two plunger poles.

The two cylinders were introduced with the idea of bringing the load under better command, and meeting the difficulty of the variation in the height of the lift; but the advantage of this plan is questionable. The duty performed by these engines is ninety millions of pounds, raised 1 ft. high with 1 cwt. of coal; and the effective force 350 horse power. The stroke of the pumps being 10 ft. and the lift 13 ft.; 80 tons of water are lifted per stroke, and only 63 tons discharged.

When working for a trial, with a 10 ft. lift, and all the pumps in full action, 109 tons of water were raised per stroke.

The consumption of fuel is 2½ lb. per horse power per hour when working with a net effect of 350 horses.

The cost of each of these engines was 21,000*l*., and the buildings and machinery 15,000*l*.—a total of 36,000*l*—or rather more than 100*l*. per horse power, with all the disadvantages of bad foundations, distance, &c. &c., and it is calculated that there will be a saving of 100,000*l*. in the cost of the works over the ordinary system of steam engines and hydraulic machinery, and 170,000*l*. over the system of windmills hitherto prevailing in Dutch drainage. The annual cost of the three methods is thus estimated: By three of these engines, 4500*l*.; by windmills, 6100*l*.; and by ordinary steam engines, 10,000*l*.

For drainage purposes there is evidently a very large economy

Digitized by Google

in the use of engines of this sort. The low rate of consumption of fuel in their case is certainly not likely to be arrived at with rotary engines employed for the same purpose.

The three engines above referred to were manufactured and erected by Harvey and Co., of Hayle Foundry, Cornwall, assisted by the Perran Company, of the same place.

One reason why Cornish engines are so costly is, that they are necessarily made strong enough for 1000 horse power to give only about 250 horse power; for instance, a cylinder 100 in. diameter, and 40 lb. steam, has the enormous strain of 140 tons on its piston at the commencement of the stroke. This gives a strain on the fulcrum, or gudgeon, of the beam of 280 tons, which easily accounts for the great strength and quantity of material used in its construction; while with two double-acting cylinders connected to one crank shaft, and having the same speed of piston, the strain on the piston is only one-fourth of the above—namely, 35 tons; and if the crank-engine piston travels quicker per minute (which it can do with ease and safety), the strain is again reduced in proportion.

When coal costs 10s. per ton for an engine working twelve hours per day, and we make various so-called improvements in that engine that will increase the first cost as much as 10*l.* sterling per horse power, we shall gain no true economy unless there is a saving by those improvements in the consumption of the coal of more than 1 lb. per horse power per hour.

From this we may conclude that where coal is very cheap, it is certainly advisable to have an equally cheap engine. Elaborate expansion, condensation, &c., is not economy in this case.

When coal is a little dearer, we ought to study expansion. With a still higher price add condensation, next steam jackets, and so on, until we have the best engines where fuel is exceedingly expensive.

DISCUSSION.

Mr. Olrick said that as the original invention of the double-cylinder engine was intimately connected with the discovery and first application of the principle of expansion, it would only be just to state that Jonathan Hornblower, an engineer in Cornwall, was the first who invented the double-cylinder engine in 1776, when he built a small engine with cylinders of 11 and 14 in. diameter. He published his invention in 1781, when he also mentioned the surface condenser. The admirers of James Watt base their assertion, that he was the first to discover the principle of the expansion of steam, upon a letter written by Watt to Dr. Small in 1769, in which he clearly described the principle of expansion. But the fact was that he never applied it in practice until

Digitized by Google

1776, when he altered an engine at the Soho Works to work expansively, and he did not publish his invention in reference to expansion until eight months after Hornblower had published his. This was even admitted by Watt himself. Consequently the expansive use of steam was the original and independent invention of both Hornblower and Watt. Although Hornblower's double-cylinder engine was for some time in hard competition with Watt's single-cylinder engine, the struggle could not be kept up, as the double-cylinder engine could not be worked well without using Watt's separate condenser, invented in 1769; and, secondly, the steam used at the time was of so low a pressure that little benefit could be gained from expansion. The principle of expansion was therefore discontinued for some time, until Richard Trevithick and Arthur Woolf again took it up about the same time, both using high-pressure steam, which Trevithick applied to Watt's single-cylinder engine, and Woolf to Hornblower's double-cylinder engine. Woolf was a very skilled mechanic, who improved nearly every part of the engine, but the principle was the same as Hornblower's, and consequently it was no more "Woolf's engine," although called so, than the present Cornish engine would be Trevithick's. Woolf's first engine was erected in Meux's brewery in 1806, but only a few others were erected for some years, as he returned to Cornwall in 1813, where he was very successful, and made a great many engines, and increased the duty from 20 million (Watt's standard) to about 60 million lbs. raised one foot high, with the consumption of one bushel or 94 lbs. of coal, thereby saving 66 per cent. of fuel. There was then for some time a hard competition between Trevithick and Woolf, but the double-cylinder engine being more expensive and complicated, and the single-cylinder engine giving as much effect, Hornblower and Woolf's engine had again to retire from the race, and the single-cylinder engine with high pressure came into general use in the form that had been retained up to the present day. Thus, although the double-cylinder engine was the first in which the principle of expansion was first introduced, and thirty years later was also the first in which this principle was made effective and advantageous, yet in both cases it was ultimately superseded by the more simple form of engine.

It was not revived successfully before being introduced in 1848, on the extension of the Lambeth Waterworks Company. Those four engines of 600 horse power, built by Simpson, in Pimlico, had done a duty of 81½ millions of pounds per bushel of coal during a trial of twenty-four hours. Engines built by the same firm for the Chelsea Waterworks Company, and also for the New River Company in 1854, did a duty of 94 millions during eight hours' trial; but during another trial with the engines of

Digitized by Google

the Chelsea Waterworks, lasting for twenty-four hours, they did a duty of only 87 millions. This was inclusive of the power consumed by the engine and pump.

In comparing the single-acting Cornish engine with the double-acting engine with crank and fly-wheel, it was impossible to lay down a rule for when one should be used and when the other. The circumstances in each individual case were to be considered, but still it must be remembered that a double-acting engine would do about three times the work of a single-acting engine—that was, for the same size and weight—and as it used steam on both sides of the piston, and worked generally twice as fast as a single-acting engine, hence for the same power was much more economical in the first cost.

It had been said by Mr. William Pole, and illustrated by Watt at an early period, that there was no theoretical advantage in whatever form of engine was used, whether double or single cylinder, as regarded economical effect of expansion. That might be or not, but taking it for granted that that assertion was correct, it was quite a different thing in practice; that was, when the expansion exceeded three or four times, and he (Mr. Olrick) maintained that where an expansion of nine or ten times was required, it could only be done successfully and effectually in a double-cylinder engine.

By taking, for instance, a double-cylinder engine with nine times expansion, the otherwise tremendous blow of the high-pressure steam on the large piston was avoided by letting the steam first into the small cylinder. From thence it passed into a cylinder of three times the area of the small one, after having been cut off at one-third part of the stroke, thus reducing the high-pressure steam three times before it entered the larger cylinder, and consequently there was the same total steam pressure on both pistons. The advantage of the vacuum acting upon a much larger piston than in a single-cylinder engine, made amply up for the back pressure against the small piston.

The results got at by some engineers in the navy of the United States, that there was not only no gain by expansion, but even a positive loss, contrary to the experience of all engineers in this country, could simply be accounted for by their experiments being carried on with steam of only a low pressure, by the steam not being in any way superheated, by the cylinders not being steam-jacketed or otherwise protected.

As to boilers, it was a well-known fact that without a good boiler the utmost amount of saving could not be effected by the engine only. They knew that the reason why Cornish boilers were so efficient in Wales was, because they were made two or three times larger than in other places, but that could not be done

Digitized by Google

in a town like London, nor could the system be carried out on board ship. He then referred to some experiments made by Mr. John Elder, of Glasgow, with the view of finding out the temperature at the different parts of a Cornish boiler, which was 33 ft. long and 5 ft. 6 in. in diameter, with two internal flues of 19 in. diameter. It was found that the temperature over the fire was 3200 deg., over the bridge 1730 deg., on entering the centre flues 1163 deg., on leaving them 800 deg.; thus the furnace of 2 sq. ft. per horse power reduced the heat 1500 deg., the shell of boiler of 18 sq. ft. per horse power 600 deg., the flues of 20 sq. ft. per horse power only 350 deg. It would thus appear that, although there was a large amount of heating surface, the evaporative power was very inferior, as the amount of heat taken out of the gases was very small; the conclusion was that the gases passed along in straight lines, and only the thin strata in contact were cooled down. Only 6½ lb. of water was evaporated per pound of coal. This showed that our land boilers were still very defective, and he (Mr. Olrick) would therefore call the attention of the meeting to a boiler constructed by Mr. Field, a member of the Society, which, for instance, for a boiler of 100 horse power only took one-twenty-fifth of the space of Cornish boilers for the same horse power, and would evaporate nearly 11 lb. of water per pound of coal.

He then showed a number of indicator diagrams from a pair of double-cylinder engines, not taken on a trial trip on the measured mile, but regularly during voyages extending over 10,000 miles. The average consumption of coals was only 2⅝ lb. per indicated horse power. He (Mr. Olrick) considered Mr. Elder's arrangement of double-cylinder engines a great improvement on the usual system, where the pistons worked simultaneously. In the engines in question the cylinders were close together, but the pistons worked in opposite directions, the consequence of which was that no steam was lost in long steam passages.

Mr. Latham thought that as regarded the requirements for a pumping engine, the Cornish engine was most decidedly superior to any other in point of economy. He had had practical experience with both the Cornish and various kinds of rotative pumping engines, and he had found that a good Cornish engine would raise three times the quantity of water that could be raised by a horizontal engine working three pumps from a three-throw crank with the same expenditure of fuel. The great economy of the Cornish engine lay in the development of the expansive principle, and also in the fact that the machinery of the engine in no way interfered with the freedom of the expansive action. This of itself was a great advantage, as the suction

Digitized by Google

valves were opened suddenly and the pump speedily filled. It was, moreover, an engine that would indicate at once to the engineer in attendance if it was not performing its duty; therefore, on this head, it was vastly superior to an engine having a heavy fly-wheel, which would neutralise any inequality in the speed of the engine when it was not performing its duty. Mr. Olrick had compared the engines of a steam vessel, and the duty performed by such engines, with the duty of a Cornish engine, but the figures he had referred to alluded to the indicated duty of the engine and not the actual duty. There was a marked difference between the two—a difference that was nowhere more perceptible than in a rotative engine when applied to pumping water, and which he (Mr. Latham) had found to exceed the actual duty by more than 100 per cent. In all machinery, whether applied to pumping water or otherwise, adaptation must be studied; and he was of opinion that a rotative engine, when applied to pump water, was defective owing to the slow motion at the beginning and end of the stroke. When the connecting rods were passing the centres the valves either did not open sufficiently early, or they remained open longer than necessary, and consequently there was a very considerable slip of water, amounting very often to as much as 30 per cent. of the capacity of the pump. It was well known that the work done by expansion was expressed by the hyperbolic logarithm of the number of times the steam was expanded: thus, if the steam was expanded 8 times, or cut off at one-eighth the stroke, as was the case in many Cornish engines, the work done was 3.08 times what the same steam would have performed if working without expansion, so it was clear that an expansive engine cutting off steam at one-eighth the stroke would save two-thirds the fuel that would be required by a non-expansive engine to perform the same duty.

Mr. QUICK, jun., said it was very desirable to ascertain the comparative duties of the various sorts of pumping engines, but it was useless to give the result of experiments unless the quality of the coals used was stated. It was supposed that the duty of Cornish engines had fallen off of late years, but this was so only nominally, as the fact was that now, instead of using the best coal as formerly, small coal—in fact, coal-dust—was employed. Again, he preferred taking the result of a year's working of an engine to being guided by experiments extending over very short periods. He complained that the advocates of the double-cylinder fly-wheel engine had given no *facts* as to the amount of duty performed by engines of that class during any length of time, although ample opportunities existed for such information being obtained. On the contrary, the author of the paper had given them the positive results of many years' working of Cornish

Digitized by Google

engines, and from his own experience he could vouch for the accuracy of those statements. In conclusion, Mr. Quick stated that he believed the single-acting Cornish engine to be the most economical for waterworks purposes.

Mr. Morris thought that the double-cylinder engine was particularly applicable to drive millwork, where uniform rotary motion was an object, but this was not required in pumping engines. In the single-acting Cornish engine there was no fly-wheel to check the high initial velocity imparted to the engine by the sudden impact of the steam on piston, but with a fly-wheel if it were attempted to commence the stroke with such a velocity, something must give way, the crank or connecting rods would be broken, or the engine be shaken all to pieces, therefore expansion could not be carried out so effectually as in the Cornish engine. He did not know what sort of boiler Mr. Elder experimented upon, but he knew from experience that in Cornish boilers with slow combustion, the heat of the gas escaping into the chimney did not exceed 400 deg. He could not agree with Mr. Fraser as to the great superiority of the single-acting pump; the duty obtained with double-acting pumps at the Kent Waterworks was about 70 millions as against 63 millions as stated in the paper. Double-acting pumps equalised the flow of water through the pipes, and required no stand-pipe. He had further equalised the flow of water by proportioning the areas of the plunger and bucket to the varying speed of the Cornish engine. In Simpson's pump the area of the plunger was half that of the bucket, the up and down strokes being made in the same time, but with the Cornish engine the up stroke of the pump was twice as quick as the down stroke; the plunger was, therefore, made two-thirds the area of the bucket, and delivered twice as much water as the bucket, but as it took twice the time a regular flow was produced. There could not be a question as to the superiority of the Cornish engine; but it was sometimes stated that the cost of enginemen was much greater than with fly-wheel engines. Now, though he deprecated such an argument, as he thought nothing could be more disgraceful than for employers, for the sake of a trifling economy, to commit the charge of engines and boilers to unskilled and ignorant men, still he should like to know how much less the cost of driving engines in the manufacturing districts was as compared with that of the mining districts of Cornwall.

Digitized by Google

April 18*th*, 1864.

H. P. STEPHENSON IN THE CHAIR.

ON THE CORNISH PUMPING ENGINE.

By A. FRASER.

ADJOURNED DISCUSSION.

Mr. W. T. CARRINGTON said he thought they were all greatly indebted to Mr. Fraser for his valuable and interesting paper. He had brought many facts to notice which had been forgotten, or perhaps never known. It was a paper that was well worth reading a second time, but the reader must have other facts before him, or he would soon be as much in favour of Cornish engines for *all* pumping purposes as the author himself.

Therefore, before making any remarks upon the paper itself, he proposed to lay before the meeting some particulars respecting various fly-wheel pumping engines, together with the results of experiments, and the opinions of several eminent engineers, in order that members themselves might draw their own conclusions as to the comparative advantages of the several classes of engines used for pumping purposes.

It might be interesting to the meeting to have some particulars of the pumping engine of the Brooklyn Waterworks, as a great mistake was made in designing and constructing that engine, which had afterwards to be rectified at great cost before it could be made to work with any efficiency.

This engine belonged to the municipality of Brooklyn, and was employed in supplying that city with water from a number of connected ponds. It was situated about six miles from Brooklyn, in a spacious and handsome brick building, and elevated the water 160 ft. into a large reservoir, whence it flowed to the city through pipes. The main, connecting the engine and reservoir, was of cast-iron, 3 ft. in diameter and 3450 ft. in length, and was laid in a straight line, with but one vertical curve of 800 ft. radius.

The entire weight of the machinery, including engine, pumps, boilers, and all appurtenances, was 440 tons.

The engine was a condensing one, and consisted of one vertical, double-acting cylinder, steam-jacketed on the sides but not on the ends, which were, however, hollow, and filled with powdered

Digitized by Google

charcoal for a non-conductor. The piston actuated a cast-iron beam weighing 25 tons, supported overhead by cast-iron standards on each side, bolted to the bed plate.

From this beam the motions were taken for the engine air pump, and for the two water pumps.

The cylinder and standards rested upon and were bolted to a strong cast-iron bed plate, extending the whole length of the engine, and secured to the masonry of the foundations. The boxes of the main centre of the beam were of cast-iron, lined with Babbit's metal. The air pump was vertical and double-acting; it had a stroke of 5 ft., and was worked from a journal half-way between the main centre of the beam and its end centre, opposite the cylinder.

The condenser was a cast-iron cylinder of 4 ft. internal diameter, with a domed top, in the centre of which the exhaust steam was discharged. The air pump and condenser were bolted, side by side, to a channel plate containing a foot valve, and situated below the bed plate of the engine. This channel plate was bolted, independently, to the stone foundation. The bottoms of the condenser and air pump were upon the same level, but the top of the condenser rose above the top of the pump, so as to allow an upper horizontal channel way, parallel to the lower one, and containing a foot valve. A solid plate, with raised ledge, was placed within the condenser, just below the upper channel way; it extended half across the condenser, and intercepted half the injection water, which was drawn off into the upper part of the pump, while the remaining half was drawn off into the lower part. The pump piston was solid, and packed in the usual manner with hemp. The air pump foot valves were of gum, and seat upon brass grillages. The lower delivery valve was the same, but the upper delivery valve was in the form of a floating top, or large disc valve, surrounding the pump piston-rod, which acted as a guide for it, and seated upon wood let in a groove in the top of the pump barrel. This barrel was of cast-iron, lined with brass. The injection water was obtained from the same well that supplied the water pumps, and into that well it was again returned, after passing through the condenser and air pump, so that after being used for condensation it was carried to the reservoir by the water pumps.

The steam piston was of cast-iron, ribbed and hollow, and was packed with cast-iron rings set out by steel springs; there were two rings, one behind the other. The cylinder valves were of the usual double poppet kind, balanced, one for the steam and one for the exhaust, and as the cylinder was double-acting, a similar valve chest and valves were required at each end; the two chests were connected, in the usual manner, with a vertical steam and

Digitized by Google

exhaust side pipe of 20 in. diameter. The steam was cut off by the steam valve, which was made to act as an expansion valve also, by means of a momentarily variable tripping apparatus, that detached and dropped the valve by its gravity, while it was prevented from slamming into its seat by a dash-pot arrangement of air, cylinder and piston attached to it.

The lift of the steam valve was only $\frac{7}{8}$ in.; the lift of the exhaust valve was 4 in. Both valves were raised and seated quickly, and the exhaust valve was held nearly at its full lift during a considerable part of the stroke by the cam-like action of its gear.

The valve gear was operated by the beam, and by a small brass cylinder of 10 in. diameter, having receiving and delivering valves, and being supplied with water pressure from the main. It was, in effect, a variation of the cataract, and caused the engine to make a pause between each stroke of piston. The steam and exhaust valves opened and closed precisely at the end of the stroke of the piston. The mechanical details of the valve gear were very complicated, and it was a very costly piece of mechanism. Though automatic, it required constant attention from the engineer, as the slightest variation, either in the boiler pressure or in the vacuum, had to be corrected by the throttle. If that correction was not made, either the buffers attached to the piston-rods of both would strike the guard timbers, or else the piston would shorten its stroke, according to the direction of the variation. The first endangered the machine, the second wasted steam in the increased clearance given to the steam piston, for there was no cushioning. The demand for increasing attention was a great defect in that gear, and the practical result was that the stroke of the pistons of the steam cylinder and pumps, instead of being 10 ft. as designed, only averaged $9\frac{3}{4}$ ft.

The water pumps were two in number; they were placed at opposite extremities of the beam, and at different elevations. The lower pump was placed immediately beneath the steam cylinder. The pistons of both pump and cylinder were attached to the same piston-rod which passed through the stuffing-boxes in both ends of the cylinder, and through a stuffing-box in the pump cover. The diameter of that rod, from the cross-head to the bottom of the steam piston, was 9 in., there a square shoulder was made, and thence to the bottom of the pump piston the diameter was $8\frac{1}{4}$ in. Between the cylinder and the pump, and upon the piston-rod, was placed a cast-iron weight, of about 10 tons, carrying a buffer, beneath which was a cob-work of timbers suspended from the bed plate of the engine for preventing the piston of the steam cylinder from striking the cylinder ends when the steam

Digitized by Google

load was too great for the water load; that weight also supplied inertia at the commencement of the stroke of the piston.

The upper pump was placed at the opposite end of the beam, and upon its piston-rod, between the pump and the beam, was placed a cylindrical cast-iron weight of about 20 tons, to supply inertia at the commencement of the stroke, and to counterbalance the opposite weight, the steam piston, rod, &c. That weight was provided with buffers similar to those on the other rod, and for the same purpose; and the timber cob-work placed beneath the buffers for arresting the stroke was similarly made to the other, but was supported on the bed plate of the engine.

The water pumps delivered into a large cast-iron air vessel, cylindrical in form, with a domed top. It was 19 ft. in extreme height above the top of the entrance nozzle, and 6½ ft. in internal diameter. Its purpose was to secure, by the elasticity of the compressed air within it, an uniform movement of the water through the main. As there were two joints above the water-line for the air to leak out, it was found necessary to provide a small pump for supplying the air leakage.

That pump was 4 in. in diameter by 5 ft. stroke of piston; it was single-acting, and was worked from a projection on the air pump piston-rod. Between the pump and the air vessel there was placed a cast-iron double-seated check valve of 3 ft. diameter. That valve was expected to slide horizontally on a spindle, but its weight was so great, and its area so large, that the available pressure was insufficient to close it, and it rusted fast upon its spindle. As a succedaneum, after the completion of the engine, a valved diaphragm was placed across the air vessel above the receiving nozzle. It was fitted in the centre, with one double-seated cast-iron valve of 24½ in. diameter, opening upwards, and a number of smaller valves surrounding it, but opening downwards, and having an aggregate area less than that of the central one. The object of that arrangement was to gain time at the end of the stroke for the gentle closing of the pump valves, for the reduced area of the diaphragm valves, opening downwards, prevented the air compressed above them from returning too quickly upon the pump valves, as the rush of water through them slackened. The slamming of the pump valves was thus prevented. The vertical movement of the cylinder and pump piston-rods was directed by an elegant arrangement of parallel motions. The air vessel was at the extremity of the engine, opposite the cylinder. A handsome entablature, extending horizontally the length of the engine at the level of the top of the standards, was supported at one end from the cylinder, and at the other from the air vessel, the centre being sustained by the standards, on which rested the pillow blocks of the main journals of the

Digitized by Google

beam. A commodious gallery projected from the top of the entablature, and gave access to the beam and other upper journals. The fixed journals of the radius bars of the parallel motions were also supported by the entablature.

In the original design of the engine, it was intended to carry the steam in the boiler at a pressure of from 25 to 30 lb. per square inch above the atmosphere, and to cut it off very short, expanding about eight times; the cylinder was, therefore, made large enough to give the proper average pressure for that measure of expansion; but, upon the first trial, it was soon ascertained that the engine could not be worked with a greater initial pressure on the piston than a few pounds per square inch above the atmosphere, and that, instead of cutting off the steam at one-eighth the stroke of the piston, or at 15 in. from its commencement, it was necessary to cut it off at six-tenths of the stroke, or at 6 ft. from the commencement. Thus not only was all the imagined benefit from large expansion lost, but there were realised all the serious disadvantages of using a cylinder two and three-quarter times too large for the work it had to perform. By using an initial steam pressure in the cylinder of 25 lb. per square inch above the atmosphere, and cutting it off at six-tenths of the stroke of piston, the work done by the 90 in. diameter cylinder, with a stroke of 10 ft., would have been performed by a cylinder of the same stroke of piston, but with only 55 in. diameter. The saving would not have been in the first cost alone, but equally in the after economy; for as the friction and back pressure would have been greatly reduced in per centum of the total average pressure, and as the absolute friction and condensation of steam by the cylinder, developing equal power, would have been less, the duty would have been materially increased.

The great oversight committed, was the failure to discern the impossibility of using steam with much expansion in the case of a pumping engine, pumping by the steam direct, and unprovided with a large mass of matter on the steam side to be put in motion at the commencement of the stroke of piston, and brought to rest at the end of it. If we supposed the matter (other than the water) set in motion by the engine to have no weight, and the movement of the watery column to be uniform, then the steam-pressure on the piston at every point of the stroke would have to remain constant, in order to exactly balance the water load, whose resistance was constant and unaffected by speed. In fact, on that hypothesis, it would be impossible to either increase or decrease the steam pressure above that equilibrium, for the supply of more steam would only accelerate the speed of piston, without increasing the pressure on it, and a decrease of the pressure on the

Digitized by Google

piston by closing the communication with the boiler, would bring it quickly to rest. Under those conditions, it would be impracticable to use the steam at all expansively. But just in proportion as matter was added on the steam side, could the initial pressure be increased on the steam piston above an equilibrium with the water load; for as movement had to be given to that matter in addition to the water load, and thus endow it with momentum, the communication between the boiler and cylinder could be closed, and the steam allowed to expand as far below the pressure, equilibrating the water load, as the momentum of the matter could supplement, until the point was reached where the combined steam-pressure and momentum were in equilibrium with the water load. In a pumping engine, therefore, the maximum degree of expansion was limited by the momentum of the matter set in motion; the greater that momentum, the more expansively could the steam be used. In a word, steam could be used expansively only by advantage being taken of the inertia of matter at the commencement of the stroke of the piston, and of its momentum at the end.

In the Cornish engines employed for pumping out mines, the large weight of matter required, in conjunction with the piston's speed, to give the necessary momentum for expansions of even three and four times, was obtained from the great length of pump-rod employed—extending from the surface of the ground to the bottom of the mine. If the depth of the mine did not furnish the weight for the desired expansion, it had to be obtained by adding it for that special purpose. But in the design of the Brooklyn pumping engine, that essential provision was ignored, and an expansion of eight times was intended, with conditions that absolutely prohibited the employment of any expansion whatever. The consequence was, as might easily have been predicted, that, when put in operation, it presented the anomaly of an engine fitted with a momentarily variable expansion gear, from which great economy was anticipated, using its steam necessarily almost without expansion. That defect, after being practically developed, was attempted to be made good by the addition of about eighteen tons of cast-iron in the circumference of two semicircles of 14½ ft. extreme diameter, keyed upon a shaft receiving a vibratory movement from the piston-rod between the steam cylinder and lower pump. Those semicircles were so poised that the diameter would approach the horizontal at the half-stroke, and the vertical at the end of the stroke, in order to give, beside their momentum, the greatest possible leverage at the beginning and end of the stroke—the first for increasing the initial steam pressure in the cylinder, and the last for compensating the decreased steam-pressure by the expansion.

Digitized by Google

Those vibrating segments mainly performed the function of a fly-wheel, but in a very inferior manner, for any superfluous momentum that might exist in the wheel at the end of the stroke of the piston, passed on and was utilised during the next stroke; but whatever "vis viva" the vibrating segments might possess at the end of one stroke, instead of being utilised during the next, was worse than lost, for it was expended in producing an injurious shock upon the engine. Even with the addition of the vibrating segments, the initial cylinder pressure could not be raised above $6\frac{1}{2}$ lb. per square inch of piston above the atmosphere; and the steam could not be cut off shorter than six-tenths of the stroke of the piston from the commencement, allowing it to expand through the remaining four-tenths, after having been throttled down to 1 lb. per square inch above the atmosphere at the point of cutting off. The difference between the initial and final pressure was only about 11 lb. per square inch of piston, and that absolute quantity was the value of the aggregate "vis viva" of the whole system. The engine must work under these conditions of cylinder pressure precisely, or it could not work at all.

Again, with the Cornish system, in which the steam acted indirectly by first raising the mass of matter whose descent afterwards performed the pumping, it was of no importance that the speed of the steam stroke was both very rapid and very irregular, being greatest during the first part of the stroke, and least during the last part; for no injurious practical result would follow from raising that mass with great velocity or with great variations of velocity; but when the steam was applied to pump direct, the practical requirements were entirely changed, for it was essential that the water was started *very* slowly from its state of rest, and that any increase of velocity afterwards given was bestowed by uniform accelerations. The descent of a weight by the force of gravity admirably satisfied those conditions, and the problem with the Cornish system was simply that of two nearly equal weights: the greater, by its descent, lifting the lesser with a motion uniformly accelerated according to the laws of gravity, the force of which, however, was thus made to act with a very diminished effect as regarded absolute velocity.

In pumping, then, directly by the steam, it was practically impossible to employ a high measure of expansion without a fly-wheel, crank, and air vessel. The first, to equalise the power throughout the stroke; the second, to cause the piston to begin and end its stroke very gradually; and the last, to neutralise the effect upon the water of the two great differences in the speed of the piston at the ends and middle of its stroke. Of those three essentials, the Brooklyn engine, pumping directly by the steam, possessed but the last, and it was probable that the use of more

Digitized by Google

vibrating weight, and a higher expansion, would produce evils from irregularity of motion disproportioned to the benefit.

With the fly-wheel and crank arrangement above alluded to, it was, of course, not intended to pass the power through the shaft of the wheel. The pumping was to be done directly from the beam, and the crank was added for the purpose of measuring out the stroke exactly, of obtaining a rotary motion for the wheel, the sole function of which was to supply momentum, and to permit the use of the usual eccentric *with its simple valve gear.*

Had the Brooklyn engine been fitted with crank and fly-wheel, there would have been saved 2 in. of each stroke of the piston in clearance; for with a positive measure of the length of the stroke, the clearance at each end of the cylinder need not have exceeded 1 in., whereas the present *working* clearance was 3 in.

Instead, too, of a costly, complex, and troublesome valve gear, requiring the constant and vigilant attention of the engineer, as before stated, there might have been employed the simple and elegant eccentric, with its unequalled appropriateness of valve motion; and, finally, momentum could have been commanded for any measure of expansion desired.

The cost of such an arrangement would have been less than that of the existing one; for the vibrating segments, their shafts and links, offset the fly-wheel, its shaft and connecting-rod, leaving the difference of cost of the valve gear a clear gain. The whole system would have thus been rendered not only cheaper, but simpler; for fewer parts would have been employed, and their action would have been more reliable, economical, and satisfactory.

A paper was read, May 4, 1859, at the Mechanical Engineers', "On the Pumping Engine at the Newcastle Waterworks," by Mr. Robert Morrison, in which it was stated that the steam was maintained at 60 lb. per square inch above the atmosphere, and the engine was usually worked with the steam cut off at one-fifth of the stroke. The usual speed of the engine was twenty-four revolutions per minute, or 192 ft. per minute speed of piston; but it had been worked up to forty revolutions per minute, equal 320 ft. per minute of the piston. The pressure of the water upon the pumps, as indicated by a pressure gauge, was 80 lb. per square inch when standing, and rose to a mean of 95 lb. per square inch whilst working, equivalent to 18.6 lb. per square inch effective pressure on the steam piston, or 57 effective horse power.

Taking the coals consumed for three months, the consumption was 30 cwt. per day of twelve hours, including lighting fires, &c., or 5 lb. of coal per effective horse power per hour, and 4 lb. per

Digitized by Google

indicated horse power per hour. That was a horizontal, high pressure, expansive, and non-condensing engine, with one cylinder double-acting, coupled to a crank and fly-wheel.

Very good pump valves were designed and used by Mr. E. A. Cowper in the Crystal Palace pumping engines; they were ring valves, and the seats had annular openings 1 in. wide for the passage of the water, the lower annular opening being 7 in. diameter, and the upper one 13 in. diameter. The valve was guided by a fixed centre pin, and was prevented tilting by the length of the central guide. The area of the two annular openings was 63 sq. in., and a lift of $\frac{9}{16}$ in. was sufficient to give an equal area for the passage of the water. The weight of the valve was 37 lb., which gave a pressure of .59 lb. per square inch, which was the force required upon the area of the opening for lifting the valve, equal to about 16 in. column of water. The weight of the valve was adjusted so that the velocity with which the water passed should not cause sufficient motion to force it against the stop; the valve, in fact, was supported by the water alone, and gradually fell on its seat as the velocity of the water decreased under the control of the crank. Mr. Cowper designed a similar valve, used at the Berlin Waterworks. The diagram exhibited of the lift of that valve showed how well it worked; that was traced by the valve itself when at work. The working line was drawn on a sheet of paper moved horizontally by direct connexion with the piston-rod, and the vertical heights were full size. From that it would be seen how very close the valve was to its seat before the crank actually passed the centre; so that it was clear that with a crank engine, having valves with a low lift, and always floating on the water, there could hardly be any blow whatever at the turn of the stroke. In the case of the old butterfly valves, the valve was shut by the column of water endeavouring to return, instead of by its own weight, and therefore shut with a violent blow; and the difficulty was greatly increased by the suddenness with which the motion of the water was checked at the end of the stroke in engines without a crank. The above particulars were given by Mr. E. A. Cowper, in a paper read at the Institution of Mechanical Engineers, April 28, 1858.

In the discussion of the same paper Mr. Siemens said he thought there were cases, such as pumping from deep pits, where the Cornish plan would prove the most economical, the pump-rods falling gradually by their own weight, and being then lifted by the free action of the steam in the cylinder; but for many cases, such as low-lift pumps, the horizontal direct action construction was preferable. Mr. Samuel Lloyd considered a great

Digitized by Google

advantage was gained in the fly-wheel pumping engine, from the capability of working at even double the speed of a beam engine, and it was also much safer from accident. A case had occurred at their own works, where the pump valve gave way in a beam engine of sixty to eighty horse power, and caused the breakage of the beam, and much mischief, which would have been prevented by a crank and fly-wheel to the engine. Mr. W. S. Garland remarked that a superiority had been found in economy in a fly-wheel engine compared with a Cornish engine. In the case of a pair of fly-wheel engines erected for the New River Company at Stoke Newington, by Messrs. James Watt and Co., the result of nine months' working gave eight to ten millions per cwt. more duty than the average performance of the best Cornish engines at waterworks, and eleven millions more duty than the double-cylinder engines working at the same establishment. Mr. E. A. Cowper very truly said that in pumping engines with a crank and fly-wheel the stroke of the pump was completely controlled, and that arrangement was now universally adopted by the best makers of waterworks pumping engines. The flow or velocity of the water was more regular with a single crank engine, even if worked as a single-acting engine; for the pause, or dwell at the top and bottom of the stroke in a single-acting engine without a fly-wheel, made more irregularity in the flow of the water than the crank motion did; then if the crank engine worked double-acting, the flow of the water was of course much more regular; and when, in addition to that, a pair of such engines were coupled at right angles, the flow was so nearly regular that the ordinary air vessel made it practically uniform. (See Figs. 1, 2, and 3.) Fig. 1 showed the variation in the velocity or flow of water from a single-acting engine without a fly-wheel. The dotted line represented the mean velocity. That curve had been constructed from the actual velocities ascertained in experiments made by a committee of the British Association with the late Professor Cowper, upon the Cornish engine erected by Mr. Wicksteed at the East London Waterworks, Old Ford.

Fig. 2 showed the variation in the velocity of the water from a double-acting engine controlled by a fly-wheel, the straight dotted line representing the mean velocity, and the inverted dotted line the corresponding velocity of the water from a second double-acting engine working at right angles to the former one. And when those two were coupled together as in Fig. 3, the result was seen to be a very slight deviation from the mean line—or, in other words, a very regular flow of water. It should also be observed that a pair of engines so arranged made many more strokes per minute than it was possible for an engine

Digitized by Google

without a fly-wheel to do. And that again was another cause of the greater regularity of the flow. As waterworks companies were more enterprising than formerly, and pumped water often to six, eight, or ten miles' distance, regularity in the flow was a most important point. Fig. 4 is a diagram of pressure on the crank throughout its stroke from steam considerably expanded behind the piston. The irregularity of pressure is shown in Fig. 5, in the case of one double-acting engine; and Fig. 6 shows the great advantage of having two double-acting engines coupled together at right angles for giving a tolerably even and regular pressure.

In a paper "On the Double-cylinder Expansive Steam Engine," by Mr. W. Pole, it was stated that, in 1848, the Lambeth Waterworks Company, on the advice of their engineer, Mr. James Simpson, took the bold measure of proposing to remove their source of supply to the bank of the Thames at Long Ditton, above the tideway; and, as a part of that scheme, it became necessary to force the water by steam pumping power along a cast-iron main, 9 miles long and 30 in. diameter, from the source to the reservoirs at Brixton-hill. That problem was a difficult one, no experience on so great a length of large main having then been obtained. The great mass of water in motion along the main, combined with the fragile nature of the cast iron, rendered it essential that the motion should go on in the most equable manner, and that concussions or irregularities of pressure should be as much as possible avoided; otherwise frequent fracture of the pipes, fraught with serious consequences to the district they passed through, might be looked upon as almost certain. At the same time, from the large steam power required, it became necessary that all possible improvements in regard to economy of fuel should be adopted.

At that time the Cornish single-cylinder expansive engine, which had been introduced into London by Mr. Wicksteed, had been somewhat extensively tried for waterworks purposes, and had justified its well-known Cornish reputation for economy; but as grave objections appeared to present themselves to its use in that case, on account of the irregularity of the single-action, it was determined to ascertain whether the other form of expansive engine, the double cylinder, would not prove more applicable; and since the importance of the case required the most careful consideration, Mr. Pole was commissioned, in conjunction with Mr. David Thompson, to investigate the subject generally, with a view to the advantageous attainment of the desired economy. In commencing that investigation, it was found that the double-cylinder engine had already been to some extent revived, and that modern examples of it, some of considerable size, were work-

Digitized by Google

ing in various parts of the country. Those were visited, and their action carefully examined; but it did not satisfactorily appear that any engines then met with were sufficiently favourable instances of the application of the expansive principle. The expansion had not been carried to a sufficient extent to produce great economy, nor arranged in the best manner to attain equality of motion; and the arrangement of the valves and passages was generally so defective as to cause great loss of power and waste of fuel. Notwithstanding those unfavourable results, however, an attentive study of the principles of the engine led to the conclusion that, with a well-considered design carefully carried out into practice, the double-cylinder arrangement promised not only to be eminently suited to the case in question, but also generally to offer a more beneficial application of the principle of expansion to engines for rotary motion than could be attained with a single cylinder. In accordance with those views, when the Lambeth Waterworks Extension scheme was carried into effect, four large double-cylinder engines were designed of 600 total horse power, the working of which had fully justified the expectations entertained of their advantages; their use had been speedily and largely extended to other cases, and the soundness of the principles on which they were constructed might be said to have been fully proved.

In a paper "On Double-cylinder Pumping Engines," by Mr. David Thompson, the author was of opinion that where expansion was carried to an extent of only three or four times, the single cylinder form of engine was simpler and better than the double cylinder; but where expansion was required to a much higher degree, the double cylinder presented the only way of carrying it out successfully in practice. When the double cylinder was adopted, an ordinary expansion of not less than ten times should be effected, if it was desired to get a result corresponding with the additional complication incurred. The theory of the action of steam jackets appeared still somewhat doubtful, but there could be no doubt that with high expansion in two cylinders they were absolutely essential to a favourable economical result. With regard to the economy of fuel attained by the double-cylinder engines, it might be stated that the four pumping engines at the Lambeth Waterworks were fixed in one house, and were employed in pumping through a main pipe 30 in. diameter and about 9 miles in length; and when all the engines were working together at their ordinary speed of fourteen revolutions per minute, the lift on the pumps, as measured by a mercurial gauge, was equal to a head of about 210 ft. of water. Under those circumstances, they were tested by Mr. Field soon after being finished, in a trial of twenty-four hours' duration without stopping. The

Digitized by Google

actual work done by the pumps during this trial was equal to 97,064,894 lb., raised 1 ft. high for every 112 lb. of coal consumed; in addition to which, this consumption included the friction of the engines and pumps, and the power required to work the air pumps, feed, and charging pumps, and the pumps raising the water for condensation. The coal used was Welsh, of good average quality. Those facts were sufficient to show the fallacy of indiscriminately using the Cornish engine for *all* pumping purposes.

Mr. Charles Greaves, in a paper "On the Relation of Power and Effect in Cornish Pumping Engines over long Periods of Working," read in 1862 before the Mechanical Engineers', stated that he had been led to maintain registers of work comparable with the expenditure of materials used, which he thought might be of service to engineers, because they had been carried on through long periods of working, and therefore became data of commercial experience.

From that data he found that the actual consumption of 14.53 lb. of feed water per stroke in the 100 in. cylinder at the East London Waterworks was equivalent to 20.09 lb. per *indicated* horse power per hour—that was, under the total load of 16.58 lb. per square inch on the piston; and the average load, as measured by a pressure gauge on the main leading from the pump, being 12.81 lb. per square inch reduced to the area of the piston, the actual consumption of feed water per horse power per hour, measured in the main, was 20.09 lb., multiplied by the ratio of 16.58 lb. to 12.81 lb., amounting therefore to 26 lb. of feed water per horse power per hour. If that were evaporated at a rate of 8 lb. of water per 1 lb. of fuel, the consumption of fuel would be 3.25 lb. per horse power per hour.

In the discussion on that paper, Mr. Adamson stated that he had had at his own works an engine of about 42 indicated horse power working regularly for eight years and a half with 150 lb. steam, and with a consumption of coal of $2\frac{3}{8}$ lb. per indicated horse power per hour, and the first cost of the engine was not more than 20 per cent. of the outlay that had been mentioned of the Cornish engine.

The momentum in the plunger and "balance bob" of a Cornish engine towards the end of its stroke partly performed the duty of a fly-wheel, but in a very imperfect manner, for all the superfluous force or momentum in the fly-wheel at the end of the stroke of the piston was carried on and utilised in the following stroke; but whatever force or momentum the Cornish plunger possessed at the end of one stroke, instead of being absorbed in the next, was not only wholly lost, but was expended in giving injurious blows on the framing and machinery. Certainly provision was made

Digitized by Google

for receiving such blows by having wrought-iron spring beams and catch pins. But even supposing the blows were prevented from injuring the machinery, the power was wasted all the same.

Again, in the Cornish engine there must be a considerable amount of steam wasted at each stroke in the space which was given between the piston and the top cover for clearance. That space must naturally be greater than in a fly-wheel engine, on account of any irregularity in the length of the stroke. Irregularity there must be sometimes, so long as the downward stroke of the plunger was arrested simply by the back steam being compressed, and thus acting as a steam buffer. A very slight increase or decrease in the velocity of the plunger would compress the back steam more or less, and thus produce a variable stroke; also any slight alteration in the pressure or quantity of steam would have the same effect, so that it was self-evident more "clearance" must be allowed in the steam cylinders of a Cornish engine than in the steam cylinders of a fly-wheel engine, and therefore so much more steam must be wasted.

The steam clearance in the fly-wheel engine could be very small, because the stroke of the steam piston could never vary; the length of stroke must be always the same when controlled, as it was most effectually, by the crank.

As regarded the trial at the Ipswich Waterworks, made to ascertain the comparative duties performed by a Cornish engine and a crank engine, working, as Mr. Fraser said, under *precisely similar circumstances*, and from the same boilers, in which the result was a duty in the case of the Cornish engine of 76 millions, and the crank engine 54 millions, he (Mr. Carrington) said that the circumstances could not be precisely similar, or the result would certainly have been precisely the same in both cases, there must have been some difference in the amount of expansion of the steam, or in the vacuum, or in the pressure of the steam at the commencement of the stroke, the steam might have been more throttled in its passages, the water valves might have been different, &c. &c.; there must have been a great difference in one or more of the above ways to give a result in favour of the Cornish engine of 13 millions. It was clearly evident that with the same expansion of steam in two engines, the duty of each must be precisely alike if other things were under precisely *similar* conditions, therefore the trial was either incorrectly made, or made under precisely *different* circumstances.

Mr. Fraser stated that the large duty of Cornish engines had of late years been much reduced, and various causes had been assigned for that apparent falling off—such as the greater depth

Digitized by Google

now attained in mining operations, &c. &c.; but the most probable cause for the seeming reduction in the rate of duty was the use of inferior coal.

He (Mr. Carrington) would ask how it was possible that greater depths of mines should decrease the duty? He thought that increase of depth or lift could have nothing whatever to do with the alteration in the amount of duty. The same amount of duty could not be got from 1 lb. of inferior coal as from 1 lb. of best coal; but still that did not quite account for the falling off in the duty. Was not the loss due more to the lesser amount of expansion that was now used in the Cornish engines than formerly? Were not the experiments more accurately made at the present time? Mr. Fraser mentioned a case where the duty performed by a Cornish engine was from 100 to 110 millions of pounds weight lifted 1 ft. high with 1 cwt. of coal, and added that no doubt facilities were given in many instances for letting air into the pumps, and so arriving at a fallacious result. The decrease of duty could not simply be from using worse coal, otherwise the duty of crank engines would be decreased proportionately, instead of being increased as it now was.

He could, to some extent, agree with Mr. Fraser, that Cornish engines in peculiar cases were, perhaps, the best engines to be used; for instance, he thought they were good for pumping water from deep wells or pits, where it was necessary to have long and heavy pump rods, which could fall by their own weight, and force upwards the column of water, and were then lifted by the action of the steam in the cylinder. Here the pump rods might be made to do the duty, to some extent, of a fly-wheel.

But even in pumping water from wells it was often advisable to have two single acting pumps, in case of one being repaired, the other might be worked sufficiently quick to keep down the level of the water. In that case a fly-wheel engine was generally used. But for low lift pumps, that was, where the level of the water to be pumped was about the same level as the engine, and had to be pumped to any height, he would say that he was strongly in favour of the horizontal direct action engine, with a good heavy fly-wheel. In the first place, it had all the advantages of a Cornish engine, at about one-half the first cost. It would require only about half the space, and thus save the expense of a large and massive engine-house. Mr. Fraser stated that the first cost of a Cornish engine was more than 100*l.* per horse power. That was a great price for pumping engines, and he was sure that engineers could not be aware, or did not think, of the cost, when they were designing Cornish pumping engines. If they knew the difference of cost between the Cornish and the horizontal crank engine they certainly would not

Digitized by Google

apply the first so indiscriminately as they did. He was sure that many engine makers would gladly take any number of contracts for fixing complete horizontal high pressure, expansive and condensing crank engines, pumps, &c., at 50*l.* per horse power, thus making a direct saving of more than 50*l.* per horse power in the first cost.

Taking 50*l.* per horse power as the saving; that, at 10 per cent. per annum for interest and depreciation, would be equal to 5 tons of coal per year per horse power, at the rate of 1*l.* per ton, equal to 1.278 lb. of coal per horse power per hour when working day and night for one year; of course when working only twelve hours per day, the gain would be on each horse power 2.556 lb.

He would assume, for the moment, that a horizontal crank engine was not quite so economical, in its consumption of coal, as the Cornish engine. Then if the crank engine worked eight thousand seven hundred and sixty hours in one year, he might add to Mr. Fraser's own figures for the Cornish engine of 2½ lb. of coal per horse power per hour 1.278 lb., and thus have a total of 3.778 lb. for the crank engine, without exceeding the yearly cost of the Cornish engine.

Many engines worked only twelve hours per day, therefore, in that case, he might add to the 2½ lb. for the Cornish engine the gain of 2.556 lb., making a total of 5.056 lb. per horse power per hour for the crank engine, without exceeding the yearly expense of the Cornish engine. That quantity of coal would certainly be quite sufficient for a horizontal *non-condensing* crank engine, and being non-condensing the cost would be considerably less than 50*l.* per horse power; so that, in that case, the yearly cost would be really less than for the Cornish engine. Even supposing there would be no saving in the yearly cost, the crank engine had by far the greatest advantage, for the smaller amount of capital was more easily obtained, both in the first instance, and when new machinery was required. Mr. Fraser said, that in a pumping engine on the Cornish principle, and of the best materials and workmanship, a greater amount of working effect was obtained from a given quantity of fuel than in any machine known at the present time; and this was, to a great extent, the result of the great attention paid to the prevention of loss of heat by radiation, and the plan of using the steam at a high pressure.

Now, if good workmanship, good materials, prevention of loss of heat, and high pressure steam, were good for Cornish engines, were they not equally good for the horizontal fly-wheel engine? What was there to prevent 35 to 40 lb. of steam being used? What difficulty could there be in cutting off at one-third or one-fourth of stroke of piston?

The horizontal engine could have steam jackets, not only round

Digitized by Google

the sides, but at the ends where they were most required, because the ends exposed the greatest surface to the in-coming steam. All the steam pipes could be carefully clothed, and the boilers could be of the proper size for the best evaporation of the water. In fact, the steam could be quite as well taken care of in the crank engine as in the Cornish engine; and he was sure that, when steam was used in crank engines with as much expansion, care, and attention as in Cornish engines, the duty gained per pound of coal would never be less, and there was, therefore, a clear saving, in adopting the crank engine, of 5*l.* sterling per horse power per year, on account of the lesser outlay.

In the above calculation, he assumed coal to cost 1*l.* per ton. That price was only in exceptional cases. More generally the price for engine coal was 10s. per ton, and then high pressure, expansive, and non-condensing crank engines could be used with greater economy than Cornish engines. For—when working 12 hours per day—as much as 5.114 lb. might be added to Mr. Fraser's 2½ lb., making a total of 7.614 lb. of coal per horse power per hour, without exceeding the yearly cost of the Cornish engine with its 2½ lb. of coal. It would indeed be a bad non-condensing engine to require as much as 7½ lb. of coal per horse power per hour. Mr. David Thompson said that the consumption of Welsh coal, by the crank engines of the Chelsea Waterworks, was only 1.7 lb. per indicated horse power per hour, = 130,000,000 1 ft. high per 112 lb. of coal—actual duty done = 103.9 millions.

Mr. Latham observed at the last meeting that ordinary slide valves of crank engines absorbed much power in working. The pressure of the valve on the ports was easily and often relieved by having a ring on the back of the valve, which pressed against the valve box, the space inside the ring being always in communication with the atmosphere, cylinder, or condenser, so that those valves could be arranged, if required, to have no pressure whatever on the face of the ports. It was not always advisable to have those valves balanced, as that added, in many cases, more to the cost of the engines than was gained by such additional work.

Mr. Quick, jun., was sorry he could not fully agree with all that Mr. Carrington had communicated in his observations. His remarks took rather the character of a fresh paper on somewhat different subjects to those introduced by Mr. Fraser. As far as he (Mr. Quick) was concerned, he was going to give the experience of those who had preceded him, rather than that of his own, although he had been connected with large water companies for the last 10 or 12 years. As regarded the duties performed by pumping engines, Mr. Carrington had mentioned one that did a

Digitized by Google

duty of 97 millions; but it must be remembered that that was done for only a very short period by an engine specially prepared, and working with the very best Welsh coal. The experiment was practically of no value for the purpose of ascertaining the relative amount of duty performed by Cornish and double-cylinder fly-wheel engines. The ordinary Cornish engines, at the London Waterworks, had done for years, and did at that moment, a duty of 70 millions of lbs., raised 1 ft. high with 1 cwt. of coals, costing on the average 10s. a ton. If such a result had been accomplished by other descriptions of pumping engines, it was not within his knowledge. Since his connexion with the London Waterworks, their object, when putting up pumping machinery, had *not* been to satisfy any particular hobby, but simply, judging by experience, to erect that sort of engine which was most economical in its consumption of coal. Originally, at the works with which he was connected, various descriptions of engines had been erected; but it had been found advantageous and economical to gradually replace them with Cornish engines. No more striking instance of their comparative economy could exist than that mentioned by Mr. Fraser as having actually taken place at the Ipswich Waterworks, and he (Mr. Quick), with all due deference to Mr. Carrington, thought that statements of actual facts made by any gentleman in a paper, should be accepted as such. With respect to first cost, he (Mr. Quick) did not think that of a Cornish engine was more than of the double-cylinder engine which had been quoted. It was remarkable that, during the whole of this discussion, no one had mentioned the duty performed by any pumping engines (other than Cornish) over any lengthened period. The Berlin Waterworks engines had been referred to, but he had been told by the engineer that the duty was only 23 millions, and that it was only a question of time—and a very short time—when they would be superseded by Cornish engines. They had been told that, to work a Cornish engine, more expensive labour must be employed than in other engines; but his experience did not tell him so. With regard to the advisability of erecting stand-pipes in connexion with pumping engines, circumstances must in all cases be the guide. Where the lift was within ordinary limits—say 200 ft.—the stand-pipe was the correct thing; but in the case of higher lifts, he thought it was desirable to put up double-acting pumps, and in place of a stand-pipe, to have a large air vessel and a "safety apparatus" with a loaded valve similar to that at the Battersea Waterworks.

Mr. Perry F. Nursey said that at the last meeting the question of the relative economy of Cornish engines and crank and fly-wheel engines was mooted. Without going very deeply

Digitized by Google

into the general question, and setting aside all theoretical views, he proposed to lay before the meeting some practical particulars which he had obtained of the actual working of a Cornish pumping engine with which he was acquainted, and could, therefore, vouch for the correctness of the data.

The engine was used to work the Devon new copper mine at Ashburton, Devon, and had sunk the main shaft of the mine to a depth of 100 fathoms, or 600 ft. from surface. The engine was the ordinary Cornish of 47 indicator horse power, and 37.7 horse power useful effect, and was constructed by Nicholls and Williams, of Tavistock. It had a 30-inch cylinder, 10 ft. stroke of piston, was single acting, and steam was cut off at half stroke.

There were two Cornish boilers, each being 35 ft. long, 6 ft. diameter, and weighing 10 tons each. The working pressure in the boilers was about 30 lb. per sq. in. Previous to having the second boiler the pressure in the one boiler was 40 lb. and above.

The coal used was Welsh, and cost on the mine 13s. per ton, but that included 8 miles land carriage from the wharves to the mine. The consumption of coal was 2 tons per 24 hours, the engine working continuously.

The pump rods consisted of about 90 fathoms of 12-inch timber, and double iron rods for 13½ fathoms at bottom, weighing about 14 cwt. The pumps were fitted with 11-in. plungers, and worked with 8 ft. stroke. The average number of strokes was 7 per minute, but after a short stoppage the speed had been for a while 10 strokes per minute until the shaft was "forked"—*i.e.* the water got under. Each stroke of the pumps raised 32.9 gallons of water, so that working at 7 strokes per minute 230.3 gallons were raised per minute=13818.0 gallons, or 219.4 hhds. per hour=5265.6 hhds. per day of 24 hours. No other work was done by the engine.

The cost of tending the engine for continuous working was: Three enginemen, one at 4*l.* per month, and two at 3*l.* 3s. per month. The monthly consumption of tallow was 32 lb.; of oil, 1 gallon; of hemp, yarn, &c., 20 lb.

The engine had been at work for 10 years continuously, with the exception of one or two short periods that the mine had been idle.

Taking the above actual working figures, there appeared as a result a cost of 11d. per day of 24 hours per horse power of useful effect. That was independent of repairs, interest on first cost, and depreciation. The engines at the East London Waterworks were stated by Mr. Greaves to be worked at the rate of 12d. per horse power per day of 24 hours, including all expenses and every kind of repairs, but not interest on capital.

Digitized by Google

As regarded the main point at issue, which was the consumption of coal per horse power per hour, the above data gave 5 lb. of coal per horse power per hour for useful effect, or duty, and 4 lb. of coal per horse power per hour indicator.

Without being in any way prejudiced in favour of either one class or other of the engines under consideration, he could but take the above practical results of the Cornish as compared with the known results of the other class, as indicating in a general sense the superior economy of the latter over the former—or, in other words, as against the Cornish engine. But that was by no means absolute, for the proper solution of the question was that there were cases in which it would be bad economy to substitute the crank and fly-wheel for the Cornish. The advocates of either class must, therefore, consent after all to qualify their approval by the admission that their rule like most others was only proved by exceptions.

Mr. Owens happened to know that crank engines were very much advocated even in Cornwall, for crank engines, or horizontal condensing engines, were contracted for by him and sent into Cornwall. No one could question the effectiveness of Cornish engines when water was to be raised from a great depth, but he thought when the first cost of necessary buildings, engines, and pumps were taken into commercial account, that there would be a balance in favour of crank engines. About twelve months since, he thought, the *Engineer* published some experiments which had been made by the engineer of the Stockton and Darlington Railway with the locomotive engine, and which showed that there was a considerable saving in point of consumption over the Cornish engine. He thought if the Cornish engine were debited with interest on the first outlay, they would not hear so much about its economical advantages.

Mr. Morris thought that in the great struggle for duty which took place in Cornwall some twenty years since, that the engines were possibly shown to do a higher duty than was actually the case, by pumping air with the drawing-lift instead of solid water. If the duty was not so high as formerly, he thought it rather owing to the engines having been improved by the Cornish engineers till there was very little further improvement to be made; and, the excitement of the struggle having died out, the racing engines working expressly for duty had disappeared, but still the average duty was very creditable, though very few of the engines, from the nature of their load, speed, and fuel, were under conditions favourable to good results. Mr. Carrington had remarked that a portion of the momentum was lost when the Cornish engine stopped on completing the stroke; but it was not so, the equilibrium valve closing before the end of the stroke, a

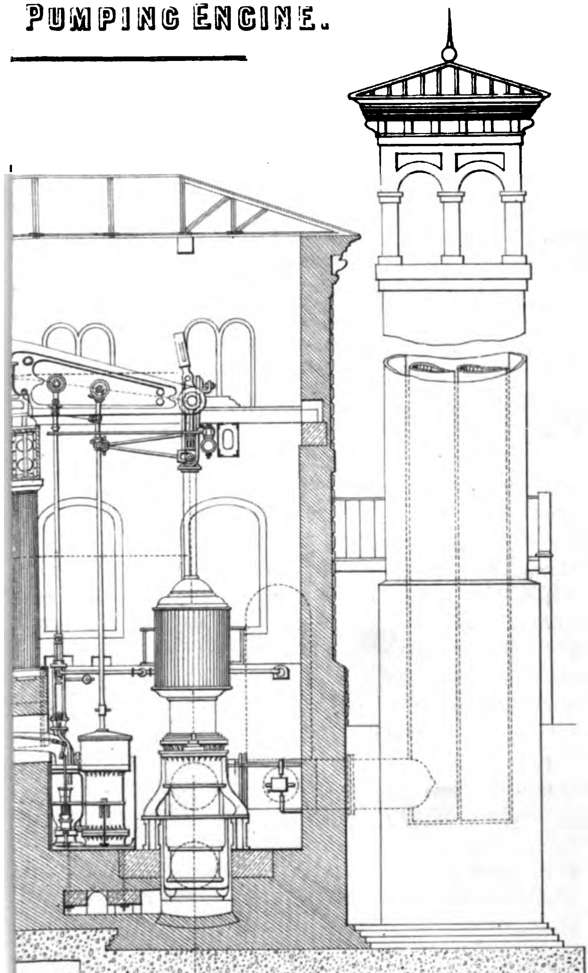
Digitized by Google

still better one of Field's improved boilers, instead of a marine boiler with salt water in, the result would, of course, have been yet more favourable to the double-cylinder engine, and the only conclusion he (Mr. Olrick) could come to was, that the Cornish engine and the Cornish boiler would now be superseded by the double-cylinder engine and the "Field" boiler.

Mr. Fraser said, with regard to the boiler referred to by Mr. Olrick, it could be seen at the Campden-hill Works. There were nine boilers, seven or eight of which were generally at work for about ten hours a day. Taking the quantity of coal per day, and spreading it over the twenty-four hours, the consumption was at the rate of $1\frac{1}{4}$ lb. per square foot of fire grate per hour. All he could say was, that he had neither seen nor heard anything to induce him to alter his opinion with regard to the superiority of Cornish engines for pumping water. As regarded the New River and the Chelsea engines, he had always been under the impression that they were much of the same character, but he had been told that one did 97 millions, and the other 130 millions. At the Grand Junction Waterworks there was a 30 in. main, nine miles in length, which had been successfully worked by a Cornish engine for years. As regarded the unequal flow of the water, that was cured by the friction of the long length of main. For any one to suppose that coal was not a question of importance, was a great mistake; seeing that the cost of coal was really increasing, the consumption of coal became more and more a question of importance. He did not know what they did in Cornwall with regard to their calculations, but in his case it was a question of actually lifting a certain quantity of water to fill a reservoir; they knew how much coal they used and how much water they raised, so that there could be no mistake about that. As regarded the cost of the Cornish engine, it was much less than 100*l.* per horse power; that amount included large buildings of an expensive character. He thought that engine, boilers, &c., did not cost more than 50*l.* per horse power. He had no hesitation in saying that if a certain quantity of water had to be raised with a certain quantity of coal, it could be done better with a Cornish engine than anything else.

Digitized by Google

PUMPING ENGINE.



OF FEET.

30 40 60 Feet

Newbery & Alexander, Lith.
13, Castle Street, Holborn.

6 Bucklersbury, London.

Digitized by Google

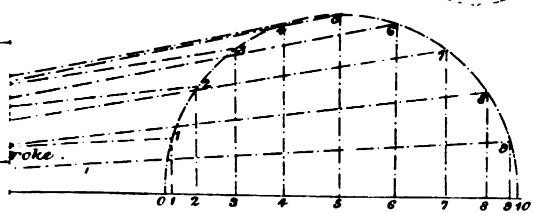
Digitized by Google

Digitized by Google

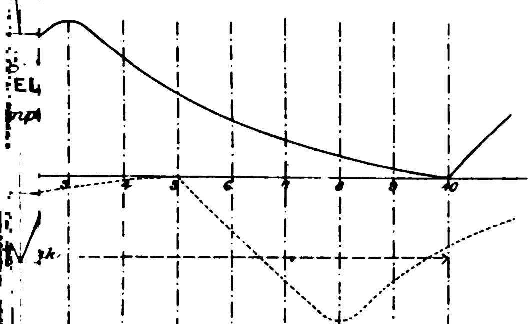
Digitized by Google

MECHAN[ICS'] INSTITUTE SAN FRA[NCISCO]

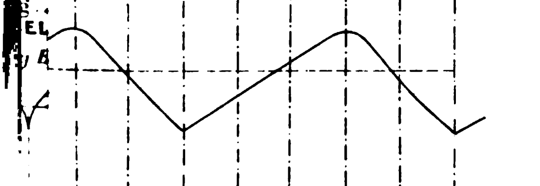
CRANK STROKE



NCINE.



AT RIGHT ANGLES.



Newbery & Alexander Lith.
43 Chancery Lane, Holborn

Digitized by Google

Digitized by Google

May 2nd, 1864.

W. T. CARRINGTON IN THE CHAIR.

ON ELASTIC RAILWAY WHEELS.

By VAUGHAN PENDRED, C.E.

THE subject of elastic railway wheels—or, more strictly, certain expedients for securing elasticity in these important members of the railway system—is one possessing much interest. Indeed, I think I am justified in saying that the adoption of certain mechanical expedients for seating tyres elastically on the wheels to which they belong, affords fair promise of enabling important changes to be introduced into our present system of constructing permanent way; while experience has shown already that, by their aid, the duration of engine tyres may be vastly increased, if not quite doubled, especially on lines of rapid curvature, and that slipping, or want of adhesion, may be reduced to a minimum.

As this is, I believe, the last night of the session, I have endeavoured to make this paper very short, in order that the discussion, which I hope you will think it worth, may terminate this evening. Many of the statements which I shall have occasion to make may appear startling, but I shall take care to advance nothing as a fact which I have not received on authority which will render it indisputable. As to any theory I may bring forward, you must take it for what it may seem worth, when you have heard me to the end.

Vast as have been the strides made during the last ten or fifteen years, I need scarcely say that the permanent way of 1864 is far from that theoretical perfection which it is so desirable it should attain. It is not only costly to make, but exceedingly expensive to maintain. The repairs of way average, I believe, in Great Britain, nearly 15 per cent. of the total working expenses; costing in England about 220*l.*, in Scotland 142*l.*, and in Ireland about 84*l.* per mile per annum. It is needless to dwell here on all or many of the causes which directly or indirectly contribute to the necessity for this great expenditure. In order that we may understand, however, how it is that seating a tyre elastically

Digitized by Google

instead of rigidly, contributes to its durability, it is requisite that we should dwell on at least one cause of want of permanence in railway track.

The paramount object had in view in the formation of a railway, is the reduction to a minimum of those forces which retard the motion of wheel carriages. Setting aside for the moment every other consideration, we may, therefore, define a perfect railway as consisting of two unyielding bars, parallel, absolutely hard on their upper surface at least, and so secured to the substructure on which they are ultimately supported, as to be incapable of moving or deflecting under the action of any practical load which they may be called on to sustain. Such a railway would not only reduce the amount of tractive force required for the propulsion of trains of carriages to the lowest limit, but would also possess elements of permanence which are wanting in any track constructed with timber sleepers, cast-iron chairs, &c., under existing arrangements; while on the other hand it would be open to certain objections which have hitherto precluded its adoption. A good engineer would meet with no great difficulty in putting down such a track—always provided he had money enough placed at his command. George Stephenson very nearly did it when he laid some of his chairs between Liverpool and Manchester, directly on the primitive rock, laid bare in a cutting, and levelled to receive them. Jesse Hartley nearly did the same thing when he built a pair of solid granite walls, and laid rails on them.

Let us suppose the case of a track composed of rails—or, rather, girders—weighing some 150 lb. or 200 lb. to the yard, with steeled tables 4 in. wide, and broad bottom flanges, bolted down directly to a substructure formed much as the old Romans formed the Appian Way, of colossal stone blocks, hewn into shape, and bedded in turn on hard rammed ballast or concrete.

Such a line would be exempt from many sources of destruction which play havoc with lines constructed on the present system. As no timber would be used in any form, rain, storm, sunshine, and frost would be set at defiance; surface water could not affect the stability of stone blocks, each weighing many cwts., and deeply seated. In these blocks the pins bolting down the rails would be securely leaded, and, therefore, the rails could not work loose. I suppose there is not an engineer present who could not, in common with myself, suggest other expedients which might be adopted in addition to any I have named, which would make such a track as practically enduring and permanent—in one sense, at least—as any of those great bridges, docks, viaducts, or other works, for the execution of which the English engineer is famous all over the world.

Digitized by Google

Such a track, in spite of all those precautions, we have reason to believe, would soon be worn out by existing engines. That is to say the rail tables would be worn out. However hard they would crumble away; however soft they would laminate. Yet even then, the cost of replacing these rails as fast as they became worn out, might be very much less than that of maintaining ordinary permanent way—a task which involves the use of new sleepers all too frequently; while the readjustment of ballast, the keying of rails in chairs, and the screwing up of fish-bolts, may be said to be one of those tasks "never ending, still beginning," which exert the heaviest drain on the purses of companies, to say nothing of the putting down of new or re-rolled rails continually. It is by no means improbable, therefore, that our theoretically perfect track, or something very like it, might have been adopted long ago notwithstanding its first cost, certain to be very great, but for another and very important consideration to which I have not yet alluded—namely, the wear and tear of engines and carriages.

Permanent way, such as I have described, would be practically rigid; in this would lie its grand defect. This, it is, which would indirectly cause the destruction of the rail tables, and lead to the speedy dissolution of engines and carriages.

This rigidity would, however, be totally different from that so-called rigidity, which is the horror of the locomotive superintendent and the resident engineer. It is not easy to find a single word which will express the action or influence exerted by a rail and its chairs and their sleepers, on each other, when resting on ballast pounded and rammed hard by the action of passing loads. I object, however, to the word "rigidity" being used to express the state of affairs in ordinary permanent way under such circumstances. We all know that the only member of the system really rigid is the unlucky ballast.

Not only is chair loose on sleeper, but rail is in turn certain to be loose in chair; thus, on the passage of each train, the rail is hammered in the chair, and the chair into the sleeper, and the sleeper on the ballast.

There is no rigidity of track here. The ballast is rigid, it is true; but it is not on it the train proceeds, but on a loose disjointed arrangement of iron and wood, interposed between the two, and suffering from the onslaught, so to speak, of both. A really rigid track, rigid and firm in all its members, bound together so that all its parts would form but one whole, would be totally different, I believe, in every respect from anything now having existence; and I am, I think, justified in saying, that we have no strictly accurate means whatever of judging of the rapidity with which rails so seated would wear out, simply because it is

Digitized by Google

very doubtful indeed if bars of iron or steel were ever tested under such circumstances since the world existed.

Now, without going to the expense of such a heavy track as I have spoken of, it is easy to see that were it but possible to introduce the use of stone sleepers, and to permit the ballast to settle its own differences with the sleepers after its own fashion, the expenses of maintenance would be greatly reduced. Good ballast always has a tendency to consolidate and become hard, but under existing circumstances this quality, which ought to be, of all things, the most desirable, is, on the contrary, regarded as a great evil, and no sooner does the ballast become hard, and the timber manifest a tendency really to sleep, than the navvy stirs them both up with his pick. This, we are told, is done to secure elasticity; but the ballast is not properly treated if it be compelled to become the elastic member of the system, to take a part for which it has no vocation, and cannot properly assume. If it were not necessary that elasticity should be provided somewhere, a very excellent track, indeed, might be made with stone blocks, and rails bolted down directly to them without chairs; and I think you will admit with me, that such a track would be infinitely more durable than any other involving the necessity for the use of wood in its construction, always provided that it were exempt from those destructive influences, to obviate the effects of which the elastic element is introduced. In other words, I believe that the elastic element in our permanent way, as it is called, is the principal cause of its want of permanence; because wood rots and wears out, because nothing has been found as yet which is better than wood under the given conditions, and because the mechanical arrangements are all so imperfect, and the bearing surfaces so small, that if that motion takes place among the parts which constitute an ordinary railway track, which the element of elasticity is presupposed to permit, they quickly become loose, and the true rigidity, on which the integrity of the entire structure depended, can only be approximately maintained by an excessive outlay of money and labour. I have little doubt that a similar conclusion has been arrived at long since by others. It is not improbable that Stephenson gave up stone blocks with a sigh of regret. Perhaps he saw dim visions of interminable timber bills looming up in the cloudy future. The history of our railway system is a record of a continual struggle on the part of the engineer to make his rails virtually, not nominally, one with mother earth; but it is likewise a record of a succession of failures, marking distinct phases of this struggle. Why? The question has been asked many a time, and perhaps answered each time, yet it is doubtful if the true answer has yet been given—if the true reason why elasticity must be introduced somewhere into our mechanical

Digitized by Google

railway system is yet accurately known. We do know that rails, if rigidly supported, wear out rapidly under the tread of rigid wheels, and that if elastically supported, their duration is greatly promoted; but to assign these facts as an answer would be to give effects as a cause. The best theory—for, after all, it scarcely deserves to rank as anything better—describes the action of wheel on rail as percussive, and thus far the theory is perfect, I have no doubt. But when we come to assign a reason for this percussive action we are rather at fault. This is of little consequence, however, because existing explanations, perfect or imperfect, almost equally well serve to show how it is, that we have much to gain by seating tyres elastically, on some one of the systems which I shall shortly have the pleasure of describing to you, and, therefore, I feel no hesitation in giving you the following explanation of the action of wheels travelling at high velocity on rails:

We find first that, for the most part, worn-out rails afford the strongest evidence that they have been exposed to the destructive effects of percussion—that, in other words, they have been destroyed by being hammered on their upper tables, and hammered into those chairs which leave so deep a mark, as well. Now, after all is said, we have still a great deal to learn about the effects produced by the collision of bodies. Above all are we ignorant of the effect produced by the instantaneous strains produced by impact. We can calculate exactly enough how many tons pressure on the square inch, the impact of a 68-pound shot on an armour plate is equivalent to, over the area which subtends the shot at the moment of collision; yet no amount of pressure would be capable of producing the effect developed by the projectile. It might not be very difficult to construct an hydraulic press which should be quite able to punch a hole in a 4½-in. plate, as well as a Whitworth or Armstrong gun, or an old 68-pounder; but the press could not produce a fracture of the same *character* as the shot. The best fibrous plate which the science of England can make has shown a crystalline fracture under the action of heavy shot, for the same reason that whenever iron is broken quickly, suddenly, it shows a crystalline fracture. These reasons I feel certain I need not delay to explain. Much of the effect of percussion on metals is due to this peculiar action. It would seem indeed as though the particles, or atoms of iron, under a hammer or any other percussive influence, were taken at unawares by the suddenness of the strain, and that, therefore, they gave way and changed their arrangement, or else parted company altogether.

Now I think I am right in stating that any powerful strain, suddenly applied, will produce precisely the same effects as actual percussion, although no striking action proper occurs, the

Digitized by Google

surfaces between which the action is to take place being already in contact.

Now to apply this to the case of a locomotive driving wheel, loaded, we will say, with five tons, and travelling at a speed of forty miles an hour. Let us first suppose the track to be practically, if not absolutely rigid—as inelastic, for example, as though the rails were seated directly on stone blocks. It is more than probable that the entire bearing surface on which the wheel would be supported would not greatly exceed one square inch; and I have no hesitation in saying that the action of that wheel on that rail would be precisely the same as that of a hammer with a weight and fall capable of striking each succeeding square inch of rail table with a force of five tons. And this action would be very different from that of a quiescent load of five tons applied gradually to any particular square inch of rail, and infinitely more destructive, each succeeding inch or half-inch of the length of rail being called on to bear a strain instantaneously imposed, and as instantaneously withdrawn. I leave you to calculate what fraction of a second is occupied by a driving wheel in passing over each inch of rail at forty or fifty miles an hour; but I think you will agree with me that a steam hammer, running two hundred blows per minute, dwells on the iron beneath it for a lengthened period by comparison. Now I conceive that the real value of the elastic element in permanent way is, simply, that it permits deflection of the rails; thereby the rail coils itself, as it were, upon the wheel, and the bearing surface may be increased, possibly from one square inch to half a dozen. Not only this, but we find, on due consideration, that the surface which has to receive the weight of the wheel is no longer exposed to so sudden a strain as that I have just referred to; because, by the deflection of the rail, and the consequent motion which takes place among its particles, the strain of the insistant weight is transmitted forward, or in advance of the revolving wheel, so that very much of the effect due to the sudden impression of the strain is absolutely done away with. Instead of a percussive effect, we have simply that of a strain gradually applied, and very much less destructive. If you have followed me so far you will have seen, then, that even with wheels mathematically accurate and perfectly smooth, we can produce an action absolutely equivalent to that of percussion in its effects upon iron on rails rigidly supported and also smooth; and that this percussive action will be developed, although the wheel and the rail are always in contact, with an effectiveness proportionate to, and regulated by, the velocity with which the wheel is caused to roll over the rail on which it is sustained. In practice we know that neither a true wheel nor a smooth rail exist; and we have thus in addition to, and irrespective of, what

Digitized by Google

I may be allowed to call the percussion of translation—true percussion, or hammering produced by the wheels jumping from one little elevation to another. Rails have been chalked near a joint a little out of level, before the arrival of a train at a high speed, and the experiment proved plainly enough that the wheels jumped over many inches of rail without touching them. Yet there is reason to believe that on good rails, well laid, and worn smooth and bright by use, this action has really very little to say to the wear of either tyre or rail.

Thus, then, we find that the percussive action of railway wheels, travelling at speed, is due directly to their rapid revolution, and is almost independent of any true jumping whatever, and elasticity operates more as a preventive of percussion than as a cure. In other words, the suddenness of strain, characteristic of percussion, is prevented, as I have just endeavoured to show, instead of being only absorbed or taken up, as might be the case if the wheel were lifted off the rail for a space, and suffered to drop.

Before proceeding further I may, perhaps, be permitted to digress for a moment. We know that tyres and axles are more liable to fracture in frost than at other times. Now, Mr. Kircaldy's experiments went to show that wrought iron is really quite as strong in frost as at any other time, or so nearly so, at least, that, practically speaking, we may consider its tensile strength as being little, if at all, affected. But we find that frost renders any track which depends on ballast for its elasticity, absolutely rigid; and, therefore, I am inclined to believe that the breakage of tyres and axles is due to the unmodified percussive action of wheel on rail which takes place under such circumstances.

To sum up what I have already advanced.

Conventional elastic way is more expensive in maintenance than true rigid way.

Conventional rigid way is more expensive in maintenance than conventional elastic way.

Most, if not all, forms of rigid way are more destructive to practically rigid wheels than almost any form of elastic way.

Percussive action is the main source of destruction, and this percussive action is always developed by the sudden application of a strain to any given area of resistance, independently of the means by which that strain is applied; and rapidly rolling wheels are, therefore, capable of producing all the effects of true percussion without ever leaving the rail.

No means have yet been discovered for preventing or absorbing percussion between revolving wheels and the rail which supports them but the introduction of elasticity somewhere into the system; and experience shows that this elasticity can be introduced with the utmost advantage into the wheel, or beneath

Digitized by Google

the tyre, instead of, or in addition to, elasticity beneath the rail or the sleeper. And if no better expedient for securing this necessary element in track can be devised than those already in use, which depend for success on soft ballast, or costly destructible timber; then I believe it may yet be found advantageous to seat rails as rigidly as possible on heavy stone sleepers, and to adopt some expedient beneath the tyres of, not the engine alone, but every wheel of the train, which shall supply that elasticity which would in such a case be absent from the permanent way. This is, however, a point open to discussion, and I advance it with diffidence, as a theory, not as a fact. And I shall now proceed to the consideration of the various expedients which have been proposed from time to time for seating tyres elastically, or some one way imparting resilience in no ordinary degree to the wheels of vehicles.

The idea of an elastic wheel is by no means new. Patent office records show that with the first notion of propelling carriages by the adhesion of the wheels on which they rested; men sought to increase that adhesion by enlarging the surface in contact with the ground, either by using a very broad wheel, or by adopting certain expedients which would permit the wheel to depart slightly from a true circular shape, and become more or less oval. The walls of this room would hardly afford space for the illustration of these schemes. I have, therefore, confined myself to the illustration of those only which are in practical every-day use, and I shall merely glance at the past history of the elastic wheel theory at present. James Neville, a clever London engineer, appears to have been the first person to take out a patent for the introduction of elasticity into wheels. This patent is dated January 13th, 1827, for an improved steam carriage for running on common roads. The driving tyres are to be made from 5 in. to 6 in. wide. When the carriage is intended to ascend very steep hills, elastic steel plates, about 18 in. long, and the same width as the tyre, are to be attached to the peripheries of the driving wheels. These plates are to be made rough on the under surface by means of projecting steel screw heads, and they are to be affixed at one end to the tyre by counter-sunk screws, so that when not compressed they will form tangents to the circumference of the wheel. The elasticity of these plates will enable them, says the patentee, to assume the circular form of the wheel when leaving the ground, while their extended surface will prevent the wheels from slipping. On the merits of this invention I am not prepared to offer an opinion, but I may remark that this Mr. Neville is, beyond a doubt, the original inventor of the multitubular boiler generally ascribed to Booth or Stephenson, and he patented it early in 1826, and pro-

Digitized by Google

posed its application to this very steam carriage in 1827. A very good drawing of this boiler is to be found in Mr. Zerah Colburn's new work on the locomotive.

The next patent was secured by William Church. In his specification, the patentee describes a running wheel, for common road steam carriages, of considerable breadth and large diameter. The felloes are composed of hoops of elastic wood, bound with an iron tyre; and the spokes consist of elastic plates of curved steel, moving on suitable points. The weight of the carriage bearing upon the axle causes the perephery of the wheel to bend into a slightly oblate figure, or flattened curve, as it passes over the road. This deviation from the circular form enables the wheel to take more firm hold of the ground; at least, so says the patentee.

The date of this invention is February 9th, 1832.

Charles Harsleben patented a friction wheel, the form whereof admits of change of shape by pressure, in 1836. This wheel was not employed as a bearing wheel, however, but was fixed on a prolongation of the axle, to act upon the ground outside of the rail. The spokes of the wheel were to be hollow, and the tyre made in as many flexible segments as there were spokes. Each segment is fitted with a rod, which enters the corresponding hollow spoke; and bears on a spiral spring located within the spoke between this rod and the nave. The segments are also connected near the ends, with stretchers attached to the sides of the spokes. These stretchers flatten the curve, which the felloes assume under pressure, and bring the surface into more extended contact with the ground.

All these expedients are indirect, and more or less unlike the arrangements adopted in modern railway practice; but we find that in 1837 Sir George Cayley took out a patent, which includes nearly all that has been done since, in the idea, at least, if not in the actual mode of application. Not only this, but we find that, in 1831, he suggested, in the pages of the *Mechanics' Magazine*, an improvement in railway wheels designed to reduce their wear, which possesses many points in common with the Griggs' wheel, which I shall shortly have to describe. Sir George writes: "If the wear and tear of railway conveyance be found too expensive, owing to the friction caused by such high pressure and great velocity, and that the use of springs to those carriages are not sufficient to remedy the evil, I think it probable that a dove-tailed groove, filled with hard oak, driven in small pieces endways within the rim of the wheels, and then turned off in the lathe, might be serviceable, and could be cheaply renewed; these pieces might be secured by a fox wedge, as commonly practised in similar cases." Sir George Cayley seems to have early seen,

Digitized by Google

with a true mechanical instinct, that there was too much dead weight transmitted along the new roads of the railway system then just bursting into life; and the experience of the last few years proves that he was right in his conclusion. His patent is for an improvement on the wheel suggested in the *Mechanics' Magazine*. In it he describes a wheel made with a deep flange, and to the opposite sides of the tyre is secured a ring, or annular plate of less depth than this flange. The space between the flange and the ring is to be occupied by a filling up of hoofs, of horns, of tough woods, or of other partially elastic substances suitable for giving a slight degree of elasticity to the periphery for diminishing the effects of percussion. You will see that all this wheel wanted was a tyre over the elastic materials, to resemble in almost every respect the Mansell wheel.

In 1838 Mr. William Bridges Adams, a gentleman to whom I need hardly say the world is indebted for many important improvements in railways and rolling stock, brought out a very ingenious elastic wheel with spokes composed of steel rings, while the tyres were seated on wood blocks or felloes. Mr. Adams' wheels were tried under his own supervision, and at one time I believe he had several sets running. The results obtained were not quite so satisfactory as he desired, principally because of certain practical difficulties met with in the construction of the wheel. Enough was done, however, to prove the great advantages to be derived from the use of elastic seating for tyres, and the experience which Mr. Adams thus gained bore good fruit subsequently.

In 1845 William Thompson patented the application of elastic bearings round the tyres of the wheels of carriages for the purpose of lessening the power required to draw them, rendering their motion easier, and diminishing the noise they make when in motion. The patentee employed for this purpose a hollow belt, composed of some air and water-tight material, such as india-rubber, and inflated it with air, whereby the wheels would in every part of the revolution present a cushion of air to the ground rail, or track on which they run. The belt, when not subjected to pressure, is of less breadth than the tyre, which is to be made much broader than usual; but that portion of the belt which is for the time in contact with the ground is extended laterally, by the pressure, to the same breadth as the tyre. And the periphery of the wheel being thereby flattened at that part, presents a more extensive surface to the ground.

John S. Templeton, in the course of a very voluminous specification, bearing date February 27th, 1846, proposed to increase the adhesion of locomotive engine wheels by forming the tyres with dove-tailed recesses, into which strips or blocks of india-

Digitized by Google

rubber or gutta-percha were to be driven, and secured by cement, or bolts and nuts. This is, in fact, Sir George Cayley's idea, re-patented.

In December, 1849, George Edmund Donisthorp patented an arrangement for constructing the driving wheels of locomotives in such a manner "that the running surface thereof shall consist each of several separate and independent parts, pressed outwards by elastic means, whereby a larger portion of the driving wheel will be constantly in contact with the rail, and thus may the driving wheels of locomotive engines be made more effective." It is unnecessary that I should enter into any further details of this invention, save only to state that the running surface of the wheel was composed of a number of blocks, located in a deep groove, and pressed outwards by a band of india-rubber.

William Pidding took a patent for improvements in wheels in 1852, which combines a vast number of impracticable schemes. The following is a specimen: "Another mode of construction consists in the use of a wheel formed of a tube of india-rubber, or other suitable material, filled with a fusible metal, such as mercury, tin, or bismuth, or any such admixture as may be found most suitable, or with certain or various resinous, waxy, or bituminous substances or compounds, which, by the application of heat, become liquified, and by that of cold resume or assume the solid state." Iron plates are to be affixed to the outside of this band or tube, "to which," says Mr. Pidding, "I convey different degrees of temperature, using heat and cold rapidly, and I thus liquify and solidify the fusible metals, or other appropriate meltable substance, in the interior of the band and the india-rubber connexions between each metallic plate, and at the side allow the band to bend when the fusible metal is liquified."

I do not ever remember hearing of a more remarkable specimen of our art than such a wheel as this would be. But we must, I suppose, admit that the ingenuity displayed in its design is so great that it cannot be measured by common minds, and that therefore a thankless world has not appreciated as it deserved this beautiful scheme. I am quite at a loss to determine for what purpose such a wheel could be required, and will therefore pass on.

Thomas Allen patented a spring wheel in 1852, in which the spokes were formed like C carriage springs, being fixed at one end to the nave and at the other to the tyre. The tyre might be composed by continuing the spring spokes, and bending the super-requisite lengths into the circular form, and covering the whole with a band of vulcanised rubber.

Now in all these inventions, save Mr. Adams's, we find that the patentees or projectors propose to apply the elastic medium

Digitized by Google

directly to the rail, or surface of the ground; and in this lay the impracticability of their schemes. It does not require much knowledge to show that an india-rubber belt, however good, would be worn out in a day or two at the most, by one of our heavy locomotives, with four or five tons on each driver. Uriah Scott, however, comes after Mr. Adams, walking in his footsteps in some degree—in March, 1855, writing as follows: "I will now proceed to describe my periphery or filly, which, like my nave, may be either constructed of wood or iron. If the latter, it will simply resolve itself into a double tyre, between which I introduce cushions of india-rubber, or other elastic material, secured by screws both from the inside and the outside, in such a manner as shall not admit of the slightest metallic connexion between the outer tyre and the inner or filly of the wheel." It is not easy to describe the principles involved in the construction of a really good elastic railway wheel in better terms. Another patent, taken out by the same Mr. Scott, in 1856, brings us up to the period when elastic railway wheels began to be recognised by those practically connected with the management of railway rolling stock. It is true that wheels made under Mansell's old patents are in one sense elastic, and were in use even before 1849; but I do not believe they were ever applied to locomotives —just the situation where elasticity is most called for. These wheels are, however, general favourites, and could their price be rendered more moderate than it is, they would, I have little doubt, be extensively used.

Setting aside one or two isolated instances of the use of elastic wheels, then; I find that Mr. George S. Griggs, locomotive superintendent of the Boston and Providence Railway, United States, was the first to seat the tyres of his driving wheels elastically, with the specific purpose of prolonging their duration, by diminishing the effects of percussion. The means he employed to attain this end are very simple. American locomotives almost invariably have cast-iron driving wheels, fitted with wrought iron or steel tyres. The Griggs' wheel, Fig. 1, is made with a number of transverse dove-tailed grooves, cast in the periphery. Into these grooves blocks of thoroughly dried hard wood, such as fine-grained old oak, or hickory, are driven in such a manner that the grain of the timber runs parallel with the axle, and across the periphery. Fig. 1 is an elevation of the rim of such a wheel, *a*, *a*, is the tyre, *b*, *b*, the cast-iron felloe, *d*, *d*, *d*, *d*, the wood blocks. When these blocks have been driven into their places, the wheel is put into the lathe, and so much turned off them that they only stand up above the surface an eighth of an inch or so. The tyre, previously turned up true inside and out, is then heated and placed on the wheel, care being taken not to scorch the blocks

on which it bears, no metallic connexion of any kind existing between the wheel and its tyre.

In the process of manufacture care must be taken that the wood is sound, of the best quality, and perfectly dry; good workmanship is also necessary, of course. When these things are provided, the most satisfactory results may be expected from the adoption of the system.

The Griggs' wheel was brought out in 1857, and has been, and is, extensively used in America. I extract the following particulars of the results obtained with it on the Boston and Providence Railway, from an official statement recently published in Boston:

"The engine Norfolk, with tyres of Bowling iron, has run a distance of 100,797 miles, the present thickness of the tyres being but $1\frac{1}{4}$ in. The load on the four-coupled drivers, each 4.5 ft. in diameter, amounting to about twelve tons.

"The Massachusetts has run 93,540 miles. The tyres are now reduced to a thickness of but $1\frac{1}{8}$ in., the load on the four-coupled 5 ft. drivers being nearly the same as in the last engine.

"The Canton has run 133,373 miles. The tyres are now reduced to $1\frac{1}{4}$ in. thick. The four-coupled drivers are 5 ft. in diameter, and loaded with nearly fourteen tons.

"The Neponset has run 62,000 miles. The tyres, of semi-steel, are reduced to a thickness of $1\frac{7}{8}$ in., the diameter of the drivers is 5.5 ft., and the load nearly the same as in the last case.

"The Mansfield, with 5 ft. wheels, loaded with $15\frac{1}{7}$ tons, has run 141,415 miles, the tyres, Lowmoor, being reduced to a thickness of $1\frac{1}{4}$ in."

I have selected these examples from many others, and when we consider how imperfect American track is, and how sharply curved, it must be admitted that the results obtained from the Griggs' wheel are nearly all that can be desired. During the time that the engines have been running these distances, the tyres have never been loose nor removed from the wheels in a single instance, and you will perceive that the thinness to which they have been worn is very remarkable, and such as we dare not attempt on a rigid seating. The fracture of an engine tyre on the Boston and Providence road is all but unknown. Yet we are told that in one winter no less than eleven engines out of twenty-two were said to be laid up with broken wheels and tyres on a line where rigid seating is employed; this statement must be taken for what it is worth; but there can be no doubt that, from the severity of the American winter, tyres are put to a more severe test than they are ever exposed to with us.

Digitized by Google

Mr. W. Bridges Adams had, as I have said, some experience with wood blocks as early as 1839. He then became convinced, however, that the system was open to constructive objections, and he has recently introduced a far more elegant arrangement, shown in Figs. 2, 3, 6, 7.

The rim of the wheel is turned slightly convex, according to the first arrangement employed by Mr. Adams. The tyre is rolled with a groove on the inside, as shown. Into this groove two hoop springs, made in segments, and each about one-third of an inch thick, are placed so as to break joint. These hoops are made of steel of the best quality. They bear only at their ends on the side of the groove in the tyre, and the convex wheel rim, resting on the centre of their breadth, is supported elastically. The tyre is secured in its place by a ring of iron sprung in at the back of the wheel rim.

A more recent modification of this wheel is shown in Figs. 4 and 5. In this, the rim of the wheel is turned perfectly flat, and only a single spring hoop is used, of the form shown in cross section in Figs. 4 and 5. This hoop is made in one piece, and forced on the wheel by water pressure after being placed in the tyre.

The tyre of the Adams' wheel, when unloaded, can be rotated on it by hand; and a slight rocking motion of the wheel within the tyre is permitted, which enables this last always to adapt itself to the surface of the rail in the best possible manner. Wheels so fitted, seldom or never slip. The area of the surface between the spring and the tyre, and the spring and the wheel rim, is so great in consequence of the circular shape of the parts, that the wheel, when loaded, cannot slip round within the tyre; and this last being elastically supported, yields slightly, becoming a little oblate, instead of remaining truly circular, and thereby takes a better hold of the rail, consequent on the increase of bearing surface. Tyres usually break from tension. But the tyres in this case, being elastically supported, can scarcely be said to be in tension at all, and it is therefore very improbable that they should break, even in intense frost. Indeed, two tyres thus fitted have been cut across for the purpose of experiment, and in that state actually did three days' work, hauling coal trains.

In the first trials of Mr. Adams' spring, which were made on the North London Railway in 1858 or 1859, the spring tyres were applied to a set of disc wheels. These tyres, of Staffordshire iron, ran a distance of 104,000 miles, with very little wear. Lowmoor tyres, rigidly seated, on the same class of wheel, were completely worn out in running the same distance.

The next trial was on the Eastern Counties (Great Eastern)

Digitized by Google

line, in the early part of 1859, when Staffordshire tyres were fitted, on the Adams' system, to the four-coupled wheels, 5 ft. 6 in. diameter, of a goods engine. These tyres were of the worst possible quality, and the springs very little better. These last broke and set, so that the tyres had to be removed, and thus far the experiment was a failure. In September, 1859, however, a pair of Cooper and Co.'s tyres, elastically seated on the same principle, were applied to the leading wheels of a tank engine on the Woolwich branch of the same line. This branch abounds in sharp curves, one of them being of but 5½ chains radius, and another of but 4¾ chains at the sharpest part. The engine had a 12 ft. wheel base, and the load on the spring wheels was 7½ tons. The tyres were applied in the manner shown in Fig. 2, the ring *a, a*, being made in two pieces, and sprung in, and the springs *b, b*, made in four segments each.

The engine began working September 21st, 1859, and ran up to July the 26th in the following year, a distance of 25,240 miles before the wheels needed re-turning. They were then replaced, and ran up to June, 1861, a further distance of 8,776 miles. At this time the tyres got quite loose, from the breakage of one or two of the springs, and the engine, requiring repairs generally, was taken out of work for a time, and the spring tyres were not replaced. The same class of tyres, put on in the ordinary way, require re-turning when they have run but 8,000 or 10,000 miles, when the flanges are found much worn; afterwards they must be turned up every 4,000 or 5,000 miles, until they are worn out. It is scarcely necessary that I should comment on such facts—for facts they are—as these.

The St. Helen's Railway, Lancashire, is perhaps more remarkable for sharp curves and heavy inclines than any other of its length (30 miles with branches) in the kingdom. The heaviest gradient is 1 in 35. The two main inclines are respectively 1 in 85, and 1 in 70. The sharpest curve has a radius of but 300 ft., while curves of but 500 ft. radius are common, and points and crossings are extremely numerous. On this line four classes of tyre have been recently tried with the following results:

Engine No. 23, Krupp's steel tyres, six wheels, four-coupled, diameter 4 ft. 6 in.; weight borne, 19 tons 15 cwt.; miles run, 40,843, when the tyres required re-turning. The wear is shown in Figs. 1 and 2, Diagram 8.

Engine No. 4, same as the last in every respect save weight—20 tons 6 cwt.; miles run, only 20,798; tyres, Hood and Cooper's best. Much worn, as shown in Figs. 3 and 4, Diagram 8.

Engine No. 27, same as the others. Tyres, best Swedish iron; load, 23 tons 17 cwt.; ran 34,006 miles, and needed turning up. Wear shown in Fig. 5, Diagram 9.

Digitized by Google

Engine No. 18. Six coupled drivers, 4 ft. in diameter only, loaded with 21 tons; tyres, Staffordshire iron, seated on double hoop springs, ran 63,913 miles before they required to go to the lathe to have the flanges reduced. Wear shown in Figs. 6 and 7, Diagram 9. We thus find that Hood and Cooper's ran only half the distance of Krupp's tyres, rigidly seated, while Staffordshire tyres, elastically seated, have run a three-fifth greater mileage than Krupp's, although the engine No. 18 was, from its construction, employed to work the heaviest gradients on the line.

One strange fact claims attention. On curves these tyres slip round on the springs the difference in the length of the rail inside and outside the curve; yet the haulage power is never diminished.

The last form of elastic seating to which I will call your attention has been recently patented by Mr. Mansell. It is illustrated in Fig. 10. The wheel rim is first turned up, and then the inside of the tyre is bored out, so that when put in place a space of about 1 in. intervenes between the two surfaces all round. This space is filled with a ring of wood (shown in cross section), teak being used by preference, on to which the tyre is forced, and secured in its place by about six segments of iron on each side of the wheel, two of which are shown in section in Fig. 10. A groove is turned in each of the tyres, and a similar groove in each edge of the wheel rim, into which raised ribs on the segments enter, while pins, as shown, pass through the wood and secure the whole in place.

These wheels have been so short a time in use that many data about their performance do not exist as yet. A good many of them are running on the South-Eastern Railway, and are, I believe, very much liked. On the Great Eastern Railway one engine has the leading wheels fitted on this plan. They have been running now some nine months, and show little signs of wear.

I think that the facts I have detailed afford fair promise that we may yet be able to resort to the use of really rigid permanent way, not that I for a moment shut my eyes to the fact that elasticity should, theoretically, be retained beneath the rail as well as beneath the tyre; but I also believe that in practice difficulties have to be encountered in constructing and maintaining elastic permanent way, which are, to say the least, very discouraging, and have little to do with the wear of rails alone. But seating tyres elastically entails no practical difficulty whatever, and so far the principle has the advantage. In any case, the duration of tyres is so much increased, and the rails spared so much in con-

Digitized by Google

sequence (for the action of wheel on rail and rail on wheel is reciprocal, and either can only be worn out at the expense of the other) that the general adoption of elastic railway wheels promises to reduce the expense of maintaining both way and rolling stock very considerably; and therefore, I think the subject is well worthy the attention of engineers.

DISCUSSION.

Mr. Colburn,* in opening the discussion, stated that he had hitherto understood that the setting of wheels elastically originated in America, and he was not aware that it had been first proposed by Sir George Cayley. Mr. Griggs, who was a cautious man, and rather afraid of new inventions, introduced the system some years since, and its merits were now widely known, and it was adopted upon a great many of the leading lines in America. The author of the paper had mentioned the results as to the mileage of tyres worked on that system. They were certainly very high, and he did not know whether a higher mileage had been attained in England. The engines in America had coupled wheels, and sand was freely used; both these circumstances being unfavourable to the durability of tyres. The amount of what was called unsuspended weight in American locomotives was a great deal more than in English engines. Many engineers forgot how large a portion of the weight of a locomotive was not supported upon the spring at all, but under the spring. Griggs's wheel, brought out in 1856, was more the result of experience in setting the chairs, and it was thought whether a system of stone blocks was not the best, if there could only have been contrived some system of supporting the rails elastically—say on india-rubber. The plan finally adopted for that purpose completely prevented the rubber from crushing out, and the rails were very well supported upon stone blocks. The author of the paper had mentioned that the original inventor of elastic wheels was Mr. Adams. Although he (Mr. Colburn) had found in the Patent Office that a patent was taken out for the same purpose as long back as 1776, yet he felt quite certain that it was original to Mr. Adams's mind. One great advantage in that system was, that it prevented the liability of the tyres to stretch, which in all tyres was a great difficulty to get over. In some cases, with the engines on mineral lines, which worked at a moderate speed, great advantage was found by having the cast-iron tyres of the driving wheels chilled. He would not like to use them himself for fast travelling, although they had been used in America for express trains.

Mr. W. Bridges Adams said it was quite evident that when one large mass of metal came into sudden and violent contact with

Digitized by Google

another mass, the result must be a blow more or less destructive in its effects. Thus the wheels did strike blows on the rails, partly induced by irregularities of surface, which incessantly broke and renewed the contact, and partly by the tension of the axles, which became springs of more or less power, while the wheels were running in paths of unequal lengths, and induced a succession of jumps by the axles alternately coiling and discharging themselves, the wheels, forming hammer heads, discharging the blows on the heads of the rails.

In his early experience, so far back as the year 1839, he (Mr. Adams) had a plan for making railway wheels with double felloes of wood break joint round a cast-iron centre, so that a deep mass of side-grain wood was interposed between the wheel and tyre, cushioning the blows. That was not quite original, he having subsequently ascertained that the principle of double felloes had been used in the early tramways. But that plan did not meet all the difficulties, and if the tyre got loose, the timber would grind away. After many experiments he resorted to the use of a spring between the wheel and tyre, and that did meet all the difficulties. As regarded the application to engine tyres there was, first, a slight flattening of the tyre on the rail, which gave a better adhesion on a larger surface; secondly, there was a lateral rocking of the tyre on the rail, thus adjusting it to varying levels across the breadth of the rail; and, thirdly, there was the facility for the wheel slipping on the springs within the tyre, thus preventing slip of the tyre on the rails, and compensating for the differing lengths of the rails on curves, and preventing mischievous tension of the axles and the jumping motion, while preventing unequal wear of couple driving-wheel tyres, and rendering bursting impossible by absence of tension. Nor was that sliding of the tyre on the wheel detrimental to traction, but the contrary, as was verified by experiment. There was nothing more in all this than might have been predicted. Reasoning from analogy, the same result might be found in the foot of a horse. When a horse had been worked over the stones for three or four years, he became what was called "groggy"—*i. e.* he stumbled in his movement. The veterinary surgeon then applied hot wires along the course of the ligaments above the hoofs, and the result was renewed steadiness; in fact, the natural springs, were rehardened and tempered. The advantages of spring tyres had, by a long course of experiment, been placed beyond dispute. Staffordshire iron tyres on springs worked against Krupps, but steel, rigidly applied, gave a result of 50 per cent. more mileage before turning up.

The results of the spring tyres had caused him to turn his attention to the possibility of elastic rails. At his suggestion, the

Digitized by Google

authorities on the North London laid down on their ordinary cross sleepers, 3 ft. apart, a pair of longitudinal timbers 4 in. deep by 11 in. wide. On those the rails were suspended by cast-iron brackets, so that the rails did not touch the timber, but were one inch above it, the brackets being spaced at the intervals between and above the cross sleepers, which, when firmly packed in the ballast, with the spaces between, below the longitudinals were left unpacked and free for drainage. The result was that, after more than two years' experience, the rails (of ordinary iron) were found absolutely undamaged on the elastic portion, though the rigid junction showed the same damaged appearance as the other portions of the line.

The rapid destruction of rails of late years under increased weights and speeds, had rendered it desirable to resort to steel rails, but he (Mr. Adams) claimed to have accomplished the same results with iron rails *versus* steel as with iron tyres *versus* steel, the elastic principles. The rule laid down in the case of steel rails was to keep them as soft as possible—*i. e.* as nearly in the state of iron as possible. If hard steel were used, it was essential that it should be homogeneous in texture, and therefore wholly softened or hardened, and tempered like a spring. If unequally hard and soft, which might be caused by placing it in the hot state on cold cast-iron plates, the steel rails were apt to break with blows. The value of the steel rail consisted chiefly in its being homogeneous, being rolled from a single ingot without a weld. The iron rail, on the contrary, was analogous to a bar of scrap iron, a mass of imperfect welding on which scale caused want of continuity. The wear by attrition was but a small portion of the evil. It was the wear or disintegration from blows that caused the difficulty. Under a blow of a certain intensity the iron rail was disintegrated, while with a similar blow the steel rail was intact. But by suspending the iron rail elastically, the intensity of blow could not be attained, and the iron rail remained as undamaged as the steel. The iron rails thus located would last certainly as long, if not longer, than the steel.

In the elastic mode of laying the line there was a contingent advantage; the load of each wheel, in the ordinary mode, came direct on each sleeper in succession, but in the elastic mode it was distributed over two or more sleepers, and the result was, that they were undisturbed in their ballast bed instead of dancing up and down under a succession of blows. The first sample was laid down with the cross sleepers 3 ft. apart, and a second sample was laid down with the cross sleepers 6 ft. apart, and the result was equally favourable; and there was no doubt that by a proper distribution of materials, the first cost of the elastic system would not be greater than the ordinary plan, while the durability would

Digitized by Google

be quadrupled. For countries where timber is inadmissible, he used cast-iron sleepers, with steel springs for the rails to rest on.

Mr. LATHAM said that a wheel should have a certain amount of elasticity to cushion the blows to which it was subjected, and also to resile from lateral concussion. One great point in making a wheel was, that it should be sufficiently strong to retain its shape; that would involve the introduction of a sufficient number of spokes, or, what was perhaps better, give the tyre a continuous bearing, as in the case of the disc wheels. It had been generally agreed that the tyre should be separate and distinct from the body of the wheel; and with regard to loose tyres, the only evil attending them was that they were likely to become elongated by the rolling action. As regarded the want of adhesion of a loose tyre to the body of the wheel, he did not think that was of much importance, as there would always be nearly the same amount of adhesion between the body of the wheel and the tyre as there would be between the tyre and the rail.

Mr. ADAMS said that there was an axiom prevalent on railways that a loose tyre was dangerous. That was only relatively to its construction. If the tyre were riveted or bolted through the tread, there was *prima facie* a reduction of strength from one-third to one-half. If the two became elongated, while confined by the rivets, it would become a polygon instead of a true circle, and the resulting blows would certainly make such a loose tyre dangerous. But if there were no through fastenings—a barbarism now fast discarding—and proper sub lips were provided, it was demonstrable that the loose tyre would be the safest, as it could not burst, and would tend to prevent tension of the axle by moving round the wheel in curves.

Mr. LEFEUVRE believed that the elasticity due to the tyre could only be infinitesimal, and that it was of very little advantage. He thought the object should be to get the elasticity in the permanent way rather than in the tyre. Although the old system, he was strongly in favour of making the tyre and wheel act as one. He thought there would be serious objections to the looseness of the tyre, the more especially on the driving wheel, because as there was a tendency to grind, so there would be a counteracting strain.

Mr. Z. COLBURN was of opinion that in the elastic wheel there was an appreciable elasticity and a considerable advantage. There could be no doubt the tyres did last half as long again; and, in his opinion, they lasted twice as long. As to the old wheels used on coal lines, referred to by Mr. Adams, he might mention that Sir George Cayley proposed precisely the same thing.

Mr. PERRY F. NURSEY said that the question under discus-

Digitized by Google

sion not only had two sides, but the extreme views of either side had its advocates in the present meeting. The author of the paper had advocated a perfectly rigid permanent way and a very elastic rolling stock, while others had argued in favour of an elastic permanent way and a rigid rolling stock. He considered the better plan to be a medium between those two, adopting neither a rigid permanent way nor a rigid rolling stock, but observing a proportional amount of elasticity in each. A duly recognised amount of elasticity was always interposed between the wheels and body of rolling stock in the form of springs; this relieved not only the rolling stock, but also the permanent way. In earlier times it was sought to obtain the hardest bearings for the rails, and stone blocks were supposed to afford all that was desired, but this soon proved itself a gross error, and was universally superseded by wood. The last relic of the old stone system he believed he had seen in course of removal some four years ago on the South-Western line between Woking and Guildford. The result of such a way was undoubtedly discomfort in travelling and injury to the stock; for when the moving load was on the rail between the bearings, it caused deflexion at that point, whilst at all the bearing points an elevation was constantly maintained. This was considerably lessened, but not altogether removed, by the timber cross sleeper system, whilst on a longitudinal timber way, such as the Great Western, or Seaton's proposed, there was continuity and an unbroken way; but this was too elastic for some, so Wright's continuous cast-iron bed plate way was held up as a model. Undoubtedly this was a first-rate road, and it cost such a first-rate price that no lines could at present adopt it. He had seen an excellent sample on the South-Western Railway. Then there was Ramié's continuous wrought-iron permanent way, which was reasonably cheap, and as all parts broke joint, it formed a good elastic way. Ramié's cast-iron tumble jaw chair, was one of many methods for obtaining elasticity at the bearings. It had been working well for some time past on the Ulster Railway. But perhaps the best example of an elastic cast-iron chair was that of Ordish's, in which it was sought to substitute iron for wood keys; to suspend the rails, so that when reversed they should not be chair worn; and to prevent the iron keys chattering or becoming loose. The elasticity of the cast iron was there fully utilised, the necessary quantity and force being given by the disposition of the metal. The top of each jaw and a portion of each wedge-shaped key was serrated, so that all parts were kept well together, and moreover admitted of regulation. Those chairs were laid on several railways; some on the Brighton Railway had been under express traffic for two years with the best results. The combination of that chair and

Digitized by Google

the heating of the bearings, and therefore of the axles, the centre bosses and spokes of the wheels, whilst the tyres were kept perfectly cold by revolving in the cold atmosphere, and continually being in contact with the cold rails, the result being a great bursting force on the contracted tyre from the expanded boss and spokes, which no doubt could at any time (as an experiment) be made to burst the tyre by the application of heat.

Digitized by Google

Fig. 3

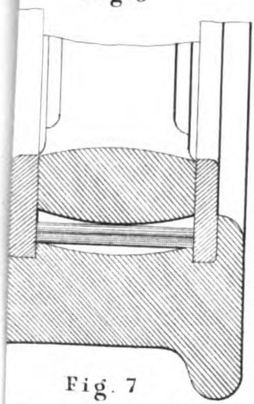


Fig. 4

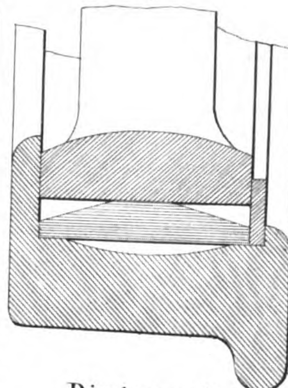


Fig. 7

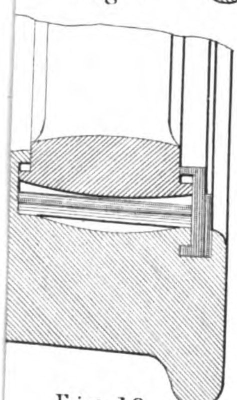


Diagram. 8

Fig. 1

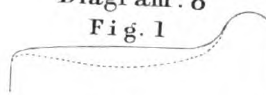


Fig. 2

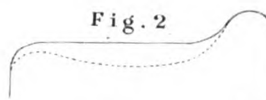


Fig. 3

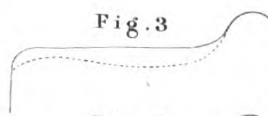


Fig. 4

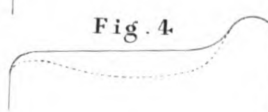
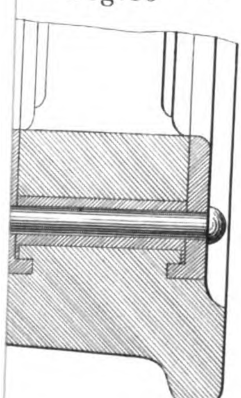


Fig. 10



Newbery & Alexander Lith
43 Castle St. Holburn.

dersbury, London.

Digitized by Google

Digitized by Google

October 3rd, 1864.

W. T. CARRINGTON IN THE CHAIR.

THE WROUGHT-IRON ROAD BRIDGES OF THE CHARING CROSS RAILWAY.

By M. Parkes.

Before proceeding to the immediate subject of the paper, it is thought a brief sketch of the line in general will not be out of place. It is, therefore, intended to describe the nature of the constructions, commencing at the Charing-Cross end of the line.

The line, on leaving the Charing-Cross station, crosses the Thames on an iron bridge of nine spans, six of them 154 ft., and the remaining three 100 ft. Commencing at the north end, the supporting works are as follows:

North abutment of brickwork, with stone beds for girders; first pier consists of nine cast-iron cylinders 10 ft. diameter at bottom, diminishing to 8 ft. and 6 ft. diameter in the case of the two outside and seven inside cylinders respectively. These cylinders are merely filled with concrete up to 5 ft. above Trinity high-water mark; the lower edge of cylinders being about 6 ft. in the London clay, and are surmounted by a cast-iron bed-plate 18 in. deep. Second pier. This is similar to the preceding, excepting that there are only five inside cylinders. Third pier. North tower of suspension bridge altered. Fourth, fifth, and sixth piers each consist of two cast-iron cylinders, 14 ft. diameter at bottom, reduced by a diminishing ring to 10 ft. diameter at low water; the lower edge of the cylinders being from 15 ft. to 20 ft. in the London clay. The cylinders are filled with concrete up to 9 ft. below low water, the remainder being brickwork, finally surmounted by granite blocks, 2 ft. 6 in. deep, in semicircles. Seventh pier. South tower of suspension bridge altered. Eighth pier, the same as fourth, fifth, and sixth. South abut-

Digitized by Google

ment, of brickwork with stone quoins and cornice, bed stones for girders of granite 2 ft. 6 in. deep.

The bridge is 46 ft. 4in. wide in the clear, from the south abutment to the third pier; it then widens out, till, at the north abutment, it is 164 ft. wide. The six 154 ft. spans constitute the "parallel section" of the bridge, and the three 100 ft. the "fan section." Each of the 154 ft. spans consists, mainly, of two trusses, 11 ft. 6 in. deep centre to centre of pins, and each weighing 190 tons, and of fifteen lattice cross girders, 4 ft. deep at centre, and each weighing 8½ tons. Each of the 100 ft. spans consists of two light trusses, so as to preserve an uniform sky line, and ten, seventeen, or twenty-four girders 5 ft. deep, according to the position of the span. The weight of the trusses is 40 tons each, and of each of the 5 ft. girders 27 tons. This section of the bridge is covered over with 6 in. planking. There is a footpath on either side of the bridge, which is carried on lattice cantilevers riveted to the cross girders on the 154 ft. spans, and to the cross girders connecting the exterior shallow girders with light trusses on the 100 ft. spans. This bridge has four lines of way between the southern abutment and third pier.

From the south bank of Thames to Belvedere-road, the line is carried on ten brick arches, 30 ft. span. On plan, this section of brickwork is of a fan shape, being wide enough between parapets at the river-end to accommodate coke-stand, water-tank and crane, and turntable, besides four lines of way; at the Belvedere-road end, there is something to spare over the usual allowance for three lines. These arches, which are formed of five rings, have a rise of 7 ft. The piers, from which two adjoining arches spring, are 4 ft. wide, and pierced with one or more 10 ft. jack-arches, according to the length. The parapet walls are 5 ft. 9 in. high above string courses, 14 in. thick, and surmounted by a cope-stone 16 in. by 5 in.

The Belvedere-road is crossed by an iron bridge, consisting of six inner working girders, and two face girders with a light parapet riveted to upper flange; the span is 46 ft. and the depth of the girders 3 ft. 6 in.

From Belvedere-road to Sutton-street, there are four 30 ft. arches, and, excepting that the clear width between parapets is 35 ft. 8 in., they are similar to those previously described, and to all other 30 ft. arches on the line.

Sutton-street is crossed at an angle of 25 degs. by an iron bridge, consisting of two main box girders, 7 ft. 8 in. deep at centre, having cross girders 2 ft. deep, riveted to their bottom flanges, for forming platform of bridge.

The line is then carried on two 30 ft. arches till it reaches the York-road, which is crossed, at a slight angle, by a bridge, con-

Digitized by Google

sisting of two single web girders, 7 ft. 6 in. deep, 70 ft. span—cross girders, 16 in. deep, being riveted to their lower flanges.

The line then proceeds in a curved direction, on seven 30 ft. arches, till Vine-street is reached, which is crossed by a bridge similar to that over Belvedere-road, excepting that the span on skew is 51 ft. Between Vine-street and Waterloo-road, there is a triangular abutment, pierced with a 10 ft. arch. The apex of the triangle is at the junction of the road and street, and the walls, which form the legs, are provided with stone girder beds for the two bridges respectively. A box girder bridge, similar to that over Sutton-street, crosses the Waterloo-road at an angle of 50 degs. The span on skew 110 ft., the depth of girders at centre being 11 ft. 8 in., and the clear width of the bridge is 40 ft. 6 in., to allow for curve of line. Between Waterloo-road and John-street, there is a triangular abutment, similar to that just mentioned, excepting that the angle at apex is made more obtuse. The bridge over John-street crosses it at so great a skew, that no cross girder is connected to both main girders. These main girders are similar to those at York-road; the lengths over all are 96 ft. 4 in. and 89 ft. 6 in. respectively, with a central depth, in each case, of 7 ft. A little beyond John-street bridge, there is a short branch connecting the Charing-Cross with the London and South-Western Railway. The branch comprises two 30 ft. arches, and an iron bridge crossing the Waterloo-road about 200 ft. from the main line bridge. There is only width for two lines on this branch. The wrought-iron bridge is 77 ft. span, and consists of two main girders, similar to York-road, 6 ft. 6 in. deep at centre; cross girders, 16 in. deep, are riveted to bottom flanges.

Returning to the main line, from John-street the line is carried over six 30 ft. arches till it reaches Cornwall-road, which is spanned by a 40 ft. brick arch of six rings; thence there is a series of twenty-two 30 ft. arches, terminating at Broadwall, over which the line is carried by an iron bridge similar to Belvedere-road. The span of this bridge is 41 ft., and the depth of girders 2 ft. 6 in.

From Broadwall the line is carried on ten 30 ft. arches to the Blackfriars-road, where there is a box girder bridge of 100 ft. span. Between this bridge and the Southwark Bridge-road, which is the site of the next iron bridge, there is a section of brick viaduct, consisting of fifty-two 30 ft. arches. The iron bridge is of the box type, and is similar to the others, excepting in the unequal lengths of the main girders; 135 ft. and 83 ft. being the respective lengths. The line is then continued by eleven 30 ft. arches to Southwark-street, the junction of the City extension. From Belvedere-road to this point there are three lines

Digitized by Google

of way; at Blackfriars-road, on the London Bridge side, the brick constructions are extended laterally for station-accommodation.

Returning to Southwark-street, this is spanned by a bridge of two bow string girders, 150 ft. long, and placed 56 ft. apart, between flanges. Cross girders are riveted and bolted to the under side of "tie" for receiving roadway plates and permanent way. The abutment at the Charing-Cross end of bridge is pierced by a 30 ft. arch, which spans Red Cross-street; the other abutment is spanned by two 10-ft arches.

From Southwark-street to York-street included, there are only two lines. This portion of the main line may be divided into three sections, as follows:

First section from Southwark-street to Counter-street, consisting of nine 30 ft. arches; second section, which is an iron viaduct carried on fifteen cast-iron columns through the Borough Market; and the third section, a bridge over York-street, consisting of four inner and two face girders, varying in length from 44 ft. to 47 ft., and 3 ft. deep; parapet 6 ft. high, of sheet iron.

Adjoining York-street bridge, at the eastern end, is another viaduct through the Borough Market. This viaduct, the site of the Eastern Junction of the City Extension, is in three spans of 45 ft., the supporting works consisting of two brick abutments, and two piers of 5 and 4 columns respectively. These columns are surmounted by a box girder, which forms a bed for the longitudinal girders, as will be explained in a subsequent part of the paper. The line, on leaving the viaduct just referred to, passes on a small piece of brick viaduct, consisting of one 20 ft., one 15 ft., and one 10 ft. arch, to Wellington-street, which it crosses by an iron bridge. This bridge is of the single web type, 118 ft. span on skew, and 36 ft. 6 in. clear width, to allow for the curve of line, which is here 10 chains.

Between Wellington-street and the South-Eastern incline is St. Thomas's viaduct, formed by one 30 ft. arch, and a V-shaped opening on either side, spanned by wrought-iron girders. The incline is crossed by a wrought-iron box girder bridge; the main girders, elliptical in shape, are 207 ft. and 176 ft. long respectively. In this bridge the main girders are not parallel with each other, being 44 ft. 4 in. between flanges at the Duke-street end, and 38 ft. at the St. Thomas's end. The curve of line on this bridge is about the same as on Wellington-street. Between the bridge over the incline and the last wrought-iron bridge on the line—namely, that over Joiner-street, there is a short section of brick viaduct, also on a curve, and comprising one 20 ft. and four 25 ft. arches. As previously stated, the Joiner-street bridge is situated at the opposite end of this viaduct to the incline bridge, and, like it, consists of two main girders of unequal length,

Digitized by Google

and not parallel with each other. The main girders are of the single web type, and 70 ft. and 52 ft. long respectively: the depth of the girders is 5 ft. 6 in.; the top chord is parallel to the bottom, and has a sheet-iron screen, 2 ft. high, riveted to it. On crossing this bridge, the down-line platform of the London Bridge Station is reached, a point at which the works may be regarded more as a lateral extension of the South Eastern works, than independent structures; it is therefore not thought necessary to continue this introductory sketch any further, but to pass on to the detailed descriptions of the wrought-iron structures.

In writing this paper, the object of the author is simply to lay before the meeting the proportions of existing works, as they are established facts fulfilling certain conditions, which enables a comparison of them to be made with any intended structure, in accordance with the principles of the mechanism of bridge construction.

In all the bridges on this line, a clear roadway, the full width of the bridge, has been secured. Excepting the Borough Market viaduct, this has been obtained by the two following methods:

First. In the case of spans up to say 50 ft., by placing shallow girders immediately under the rails for the working girders, the two face girders which have riveted to their upper flanges a sheet-iron parapet, being of lighter section. Plate 1, Figs. 1, 2, 3, 4, and 5, is an illustration of this type of bridge.

Second. In the case of larger spans, the roadway has been formed by attaching cross girders to two main girders, as shown in Plate 1, Figs. 6 to 13.

The following are the three systems of road-plating employed:

First. For the small spans, wrought-iron arch-plates, $\frac{1}{4}$ in. thick, are riveted to the top flanges of the girders. Plate 1, Fig. 1.

Second. For the larger spans, when the line is straight, longitudinal plates 16 in. × $\frac{1}{2}$ in., centred with the rails, extend from end to end of bridge: they are riveted to the cross girders; then, arch-plates, $\frac{1}{4}$ in. thick, are riveted to their sides. Angle-irons, $3\frac{1}{2} \times 2\frac{1}{2} \times \frac{3}{8}$ are substituted for the longitudinal plates at the sides of the bridge. Plate 1, Fig. 13.

Third. For the preceding case, when the line curves, the cross girder has riveted to its upper flange a $\frac{1}{2}$ in. plate, 5 in. wider than flange, and centred with it. The space between two cross-girders is then filled in with flat plates, $\frac{1}{2}$ in. thick, riveted to plates on upper flanges of cross-girders. Plate 1, Figs. 6 and 8.

Digitized by Google

There have been three types of structure employed, namely, the single web girder, the box girder, and the bowstring girder.

To avoid tedious repetition, the bridges of each type have been classed, and the details for the bridges of the same class given consecutively.

The first bridges that have been classed together are, Belvedere-road, Vine-street, York-street, and Broadwall. The spans and depths of girders are as follows:

Belvedere-road .	46 ft.	span,	3 ft.	6 in.	deep.
Vine-street . .	51	„	3	6	„
York-street . .	37	„	3	0	„
Broadwall . .	41	„	2	6	„

These bridges being so similar, it is thought sufficient to describe two only—namely, Vine-street and Broadwall.

Vine-street.—This bridge accommodates three lines of way, and consists of six working and two face-girders.

In Plate 1, Fig. 1, is a half-section of a bridge, 41 ft. span; Fig. 2 is a half-elevation of a face-girder; Fig 3 is a half-elevation of a working girder; and Figs. 4 and 5 are plans of ends of a working and a face girder respectively. The dimensions of the working girders are as follows: Top flange, two plates $\frac{7}{16}$ in. thick, 20 in. and 16 in. wide: the former is uppermost, and is prepared to receive the roadway plates; bottom flange, 16 in. wide by $\frac{3}{4}$ in. thick; web, $\frac{1}{2}$ in. thick, stiffened by having the vertical joints connected by two T irons, 5 in. × $2\frac{1}{2}$ in. × $\frac{1}{2}$ in. Rivets $\frac{3}{4}$ in. diameter, and 4 in. pitch. Each flange is connected to the web by two angle-irons, 4 in. × 4 in. × $\frac{5}{8}$ in. At each end there is a bearing-plate, 2 ft. 6 in. × 2 ft. × $\frac{3}{4}$ in., pierced with oblong holes to suit four Lewis' bolts 1 in. diameter.

For the face girders, the following are the dimensions: Top flange, 11 in. wide by $\frac{1}{2}$ in. thick, not centred with web, but 1 in. out: this is to provide for attaching the roadway plates; bottom flange, 9 in. wide by $\frac{1}{2}$ in. thick; web, $\frac{1}{2}$ in. thick, connected to each flange by two angle-irons, 4 in. × 4 in. × $\frac{1}{2}$ in. The webs are stiffened in the same manner as the working girders.

The roadway is formed of arch-plates, $\frac{1}{4}$ in. thick, with a rise of about 3 in., and riveted with $\frac{1}{2}$ in. rivets, 4 in. apart, to top flanges of girders.

On the top flanges of the working girders longitudinal timbers, 16 in. wide by 6 in. and 9 in. thick, for the lower and higher rail respectively, are placed: each pair of timbers are framed together by a transom and 1 in. bolt every 6 ft. The transoms are shown in Plate 1, Fig. 1.

For forming the parapets, an angle-iron, 3 in. × 3 in. × $\frac{3}{8}$ in., is riveted to the top flanges of the face girders, by the same rivets

Digitized by Google

that attach top flange to the $4 \times 4 \times \frac{1}{2}$ angle-iron. To this angle-iron, plates, three-sixteenths thick, are riveted. They are 6 ft. high, and of such a width, that a vertical joint occurs over each pair of tee irons of the face girders, and one between any two pairs. The vertical joints are stiffened by a tee iron, $4 \times 2 \times \frac{3}{8}$ inside, and a strip 4 in. $\times \frac{1}{2}$ in. outside. The top rail is of tee iron, the same section as the vertical ones. The rivets in roadway and parapet are the same.

The clear width between parapets is 36 ft. 4 in., which allows for the curve of line at this point.

The weight of the eight girders is 38 tons 14 cwt., and the whole weight of bridge 50 tons 14 cwt.

Broadwall.—This bridge also consists of six working and two face girders. The dimensions are as follows: For working girders—Top flange, 16 in. wide by $\frac{3}{4}$ in. thick, riveted to web by two angle-irons, 4 in. $\times$ 4 in. $\times \frac{3}{4}$ in., and pierced with holes for $\frac{3}{8}$ rivets every 3 in. on each side; bottom flange, 15 in. wide by $\frac{3}{4}$ inch thick, riveted to web by two angle-irons 4 in. $\times$ 4 in. $\times \frac{5}{8}$ in.; web, $\frac{1}{2}$ in. thick in seven sections, connected at vertical joints by two tee irons, $5 \times 2\frac{1}{2} \times \frac{3}{8}$.

At each end of girder there is a bearing-plate of the same dimensions as in Vine-street bridge. For face girder—Top flange, 9 in. wide by $\frac{1}{2}$ in. thick, not centred with web, to which it is connected by two angle-irons $3 \times 3 \times \frac{1}{2}$. The webs are the same as for working girders, and the parapet similar to Vine-street.

The girders in this bridge are braced by a system of diagonal bars, 3 in. $\times \frac{5}{8}$ in., connected to girders by means of short pieces of tee iron, riveted to top and bottom of webs about 6 ft. 8 in. apart. The road-plating is similar to that for Vine-street.

In addition to the ordinary angle-iron cover, a strip is riveted to the opposite side of the girder.

The weight of the six working girders is $26\frac{1}{2}$ tons; of the two face girders, $4\frac{3}{4}$ tons; and of the whole bridge, 43 tons.

The next class of bridge that it is intended to describe are those in which the roadway is formed by cross girders attached to two main girders of the single web type. There are five bridges of this class—namely, York-road, John-street, Waterloo Branch, Wellington-street, and Joiner-street. The preceding is the order it is intended to describe them in.

Plate 1, Figs. 6 to 10, is an illustration of a bridge of this type, 118 ft. span.

Fig. 6 is a half transverse section of the bridge to a 3 in. scale; Fig. 7, an elevation of one of the main girders to a $\frac{3}{8}$ in. scale; Fig. 10, an elevation of end of main girder to a $1\frac{1}{2}$ in.

Digitized by Google

scale; Fig. 9, an end elevation of main girder to the same scale; and Fig. 8, a transverse section of cross girder to a 3 in. scale.

York Road Bridge.—Main girders, 82 ft. 3 in. and 80 ft. 3 in. long: they are similar in other respects, and of the following dimensions: Depth at centre, 7 ft. 6 in., at ends, 6 ft.; top flange, 2 ft. 2 in. wide, consists of four $\frac{5}{8}$ plates at centre, reduced to three plates at ends; bottom flange, 2 ft. wide, consists of one $\frac{3}{4}$ and three $\frac{5}{8}$ plates at centre, reduced at ends to one $\frac{3}{4}$ and two $\frac{5}{8}$. Both flanges are connected to web by means of two angle-irons $6 \times 6 \times \frac{3}{4}$. The two web plates at either end are 2 ft. and 2 ft. 4 in. wide, and the remainder 3 ft. wide. Five plates at either end are $\frac{3}{8}$, and the remainder $\frac{1}{4}$ thick; the vertical joints are connected by two tee iron gussets, 6 in. $\times$ 3 in. $\times \frac{5}{8}$ in., except at the end joints, where four angle-irons, $3 \times 3 \times \frac{3}{8}$, and two $\frac{1}{2}$ in. gusset-plates are substituted for the tee irons. Riveting, all vertical 1 in. diameter; all others $\frac{3}{4}$ diameter.

Cross Girders.—Those connected to both main girders—the bridge being on a skew—are 39 ft. long by 16 in. deep; they are all placed 3 ft. centre to centre. Each flange is 15 in. wide by $\frac{3}{4}$ in. thick, connected to web, $\frac{1}{4}$ thick, by two angle-irons, 5 in. $\times$ 3 in. $\times \frac{5}{8}$ in. The web is divided by vertical **T** irons into four panels. The road-plating is on the second system, as shown in Plate 1, Fig. 13.

One end of each main girder rests on eight rollers, $4\frac{1}{2}$ in. diameter

The weight of the two main girders is 49 tons 16 cwt., and the whole weight of bridge is 141 tons 13 cwt.

John-street.—As previously stated, this bridge is on a great skew, the bridge on plan being of a lozenge shape. The main girders are 96 ft. 4 in. and 89 ft. 6 in. long respectively; the depth at centre 7 ft.; at ends 6 ft. Both flanges are 2 ft. wide; the top is built up of four $\frac{9}{16}$ plates at centre, reduced to three plates at ends; the bottom is built up of one $\frac{11}{16}$ and three $\frac{9}{16}$ plates at centre, reduced to one $\frac{9}{16}$ plate less at ends. The end web-plates are 2 ft. 4 in. wide, and the remainder 3 ft. Five plates at either end are $\frac{3}{8}$, and the remainder $\frac{1}{4}$ thick. The vertical joints are connected by **T** irons, the same as York-road bridge, and the horizontal by angle-irons, 6 in. $\times$ 6 in. $\times \frac{3}{4}$ in. The cross girders are all 2 ft. deep, but varying in section to suit the length: they are placed 4 ft. apart, centre to centre, and the spaces between them filled in with road-plating, on the third system shown in Plate 1, Figs. 6 and 8. Rollers are provided at one end of each main girder, as in York-road bridge. The weights of the longer and shorter main girders are 24 tons 13 cwt. and 23 tons 3 cwt.; of the cross girders, 52 tons; and the total weight of bridge, 124 tons 7 cwt.

Digitized by Google

Waterloo Branch Bridge.—This is for two lines only; the lengths of main girders are 86 ft. and 84 ft.; the depths at centre and ends, 6 ft. 6 in. and 5 ft. 3 in. Flanges 2 ft. wide, the bottom built up of one $\frac{3}{4}$ and three $\frac{5}{8}$ plates at centre, and one $\frac{3}{4}$ and two $\frac{5}{8}$ plates at end; the top flange is built up of four $\frac{5}{8}$ plates at centre, reduced to three at ends. Two angle-irons, $6 \times 6 \times \frac{3}{4}$, connect each flange to webs, which are disposed in the same way as in York-road bridge.

The cross girders are placed 4 ft. apart centre to centre; they are 16 in. deep, and consist of a $\frac{1}{2}$ web with two angle-irons, $4 \times 4 \times \frac{3}{4}$, riveted top and bottom for flanges. The length of the girder is divided into three panels by vertical T irons.

The roadway is of the second system. Plate 1, Fig. 13.

Under one end of each main girder, eight rollers, $4\frac{1}{2}$ in. diameter, are placed; the upper and lower plates for these to work between are of cast-iron, 2 in. thick; the frames are of wrought-iron, 3 in. × 1 in. The fixed ends are provided with bearing plates $\frac{3}{4}$ in. thick.

The weight of the two main girders is $49\frac{1}{4}$ tons; of the cross girders, 24 tons 16 cwt.; and of the whole bridge, 94 tons.

Wellington-street Bridge.—This is the largest single web girder bridge on the line, the length of the girders being 134 ft., and the span on skew 118 ft. The girders are 12 ft. deep at centre, and 9 ft. 8 in. at ends.

The flanges are 2 ft. 6 in. wide, riveted with six rows of 1 in. rivets. The top flange is built up of five $\frac{5}{8}$ plates at centre, reduced to three at ends. In addition to the two angle-irons which connect this flange to web, there are two other of the same size, $5 \times 5 \times \frac{13}{16}$, riveted to each edge. Plate 1, Fig. 6. The bottom flange is built up of one $\frac{11}{16}$ and four $\frac{5}{8}$ plates, reduced at ends to one $\frac{11}{16}$ and two $\frac{5}{8}$ plates. On each side of the upper side of this flange a bar, 9 in. × $\frac{13}{16}$ is riveted. This is shown in Plate 1, Figs. 6 and 10. Fig. 10 shows the way the plates break joint.

The web-plates, with the exception of the end ones, are 2 ft. 2 in. wide, the end ones being 2 ft. wide, as shown in Fig. 10; $\frac{3}{8}$ thick for a length of nine plates at either end, and $\frac{5}{16}$ for the remaining distance.

Referring to Figs. 7, 9, and 10, it will be seen that a $\frac{1}{2}$ plate is riveted to the ends of the girders by means of angle-iron gussets, 3 in. × 3 in. × $\frac{3}{8}$ in.; also, that at the two end web joints $\frac{1}{4}$ gusset plates are riveted, with similar angle-irons. After the bridge was erected, it was found necessary to stiffen the ends of the girders by attaching reverse angle-irons, $3 \times 3 \times \frac{1}{2}$ to the end and gusset plates. The intermediate vertical joints of web are connected by two tee iron gussets, $6 \times 3 \times \frac{3}{8}$, and two strips, $6 \times \frac{3}{8}$,

Digitized by Google

alternately. These strips, as shown in Fig. 3, are cranked to set over the longitudinal angle-irons.

One end of each girder was provided with a bearing-plate, 5 ft. × 4 ft. × $\frac{3}{4}$; the other end had attached to it a cast-iron plate, 2 in. thick, to bear on eight rollers, $4\frac{1}{2}$ in. diameter. The roller-beds are also of cast-iron, 2 in. thick, and further strengthened by having three ribs 3 in. deep cast on; the roller frames are of wrought-iron, 3 in. × 1 in.

A longitudinal section of this roller arrangement is shown in Fig. 10, and a transverse section in Fig. 9.

In Fig 10, the lengths of top and bottom angle *covers* are shown by the number of rivets in each. The first have 7 and 8 holes in each arm respectively, and the second 9 and 10; so that, since the rivets are 4 in. pitch, the lengths are 2 ft. 8 in. and 3 ft. 4 in.

The ordinary lengths of

Angle-bars . . .	13 ft.
Flat bars, 9 × $1\frac{3}{8}$ . .	17 ft. 4 in.
Joints to ditto . .	3 ft. 4 in.
Laminated plates . .	6 ft. 8 in.

The dimensions A.A., Fig. 10, are 16 in. each, so that they contain four rivets in the direction of length of girder each. Considering one plate only, since there are six rows of rivets, we have an aggregate of twenty-four 1 in. rivets, or a sectional area of 18.84 square inches, against 14.76 square inches, the sectional area of a bottom plate through a line of rivet holes; or an excess in area of rivets of 4.08 square inches.

The cross girders are 41 ft. 6 in. long, which makes the distance, centre to centre, of main girders 39 ft. The distance, centre to centre, of the cross girders themselves, is 4 ft. They have a central and end depth of 2 ft. and 1 ft. 4 in.; the flanges are 15 in. × $\frac{1}{2}$, connected to a $\frac{1}{4}$ web by 4 × 4 × $\frac{5}{8}$ angle-iron. The top flange has also riveted to it an extra plate, 19 × $\frac{1}{4}$, for attaching roadway plate. Fig. 8 is a section of one of the girders, showing a road-plate attached at B. The length of the girder is divided into eight panels by vertical T irons at joints, 5 × $2\frac{1}{2}$ × $\frac{3}{8}$:

At each end of the bridge there are also shorter cross girders; but, as they are the same as a 41 ft. 6 in. girder, with a piece cut off one end, nothing more need be said about them. The ends of the cross girders are riveted to the mains with 24 rivets, 1 in. diameter.

To the ends of the cross girder, a cast-iron cornice, C. Fig. 6, is bolted.

The rivets through longitudinal angle-irons and webs are 1 in.

Digitized by Google

diameter, and through vertical T irons and strips, and webs only, $\frac{3}{4}$ in. diameter.

The weight of each main girder is 65 tons; of all the cross girders, 80 tons; and of the whole bridge, 248 tons.

Joiner-street is spanned by two main girders, 70 ft. and 52 ft. long, supporting fifteen cross girders, which form the platform of bridge. The main girders are not placed parallel; the length of the longer cross girder connected to both being 51 ft. 6 in., and the shorter 47 ft. 4 in. In both main girders the top and bottom flanges are parallel to each other; the central depth is 5 ft. 6 in., and the width of flanges 2 ft.

In the 70 ft. girder the flanges are built up of five $\frac{5}{8}$ plates at centre, reduced to three at ends; in the 52 ft. girder they are built up of four $\frac{5}{8}$ plates at centre, reduced also to three at ends. In all cases the flanges are connected to the web by two angle-irons, 6 in. × 6 in. × 1 in. The vertical joints of webs are connected by two T iron gussets, $6 \times 3 \times \frac{5}{8}$. One end of each main girder is provided with a bearing-plate; the other bears on rollers $4\frac{1}{2}$ in. diameter. The 70 ft. is provided with nine, and the 52 ft. with seven rollers; to the top flanges of both a light screen, 2 ft. high, is attached by angle-iron, $3 \times 3 \times \frac{3}{8}$, which consists of a $\frac{3}{16}$ web, with top and vertical tee irons, $4 \times 2 \times \frac{3}{8}$.

The cross girders, placed 4 ft. apart, centre to centre, are 2 ft. 6 in. deep at centre, and 1 ft. 3 in. at ends. The flanges, 16 in. wide by $\frac{3}{4}$ in. thick, are each connected to the $\frac{1}{2}$ web by two angle-irons, $4 \times 4 \times \frac{5}{8}$; the top flange has a $\frac{1}{2}$ plate riveted to it, as shown in Fig. 8.

In the main girders, all vertical rivets are 1 in., and the horizontal $\frac{3}{4}$ in.; in cross girders, all $\frac{7}{8}$ in.

The weight of 70 ft. girder, $21\frac{1}{2}$ tons; of the 52 ft. girder, $14\frac{1}{2}$ tons; of all the cross girders, 63 tons 13 cwt.; and of the whole bridge, 115 tons 12 cwt.

Four similar box girder bridges will now be described—namely, Sutton-street, Waterloo-road (main line), Blackfriars-road, and Southwark-road. In Plate 1, the proportions are those of Blackfriars-road Bridge. Fig. 13 is a half transverse section. Fig. 11 is an elevation of a portion of a girder, showing rollers, a cross girder in position, and a portion of cornice.

Following the same order observed with the other bridges, we commence with Sutton-street. The main girders, in this case, are similar in every dimension except length; one girder being 111 ft. 6 in, and the other 110 ft. 6 in. The depth at centre is 7 ft. 8 in., and at the ends, 6 ft. The top flange, 2 ft. 4 in. wide, is built up of four $\frac{5}{8}$ plates at centre, reduced to three at ends; the bottom flange, 2 ft. 2 in. wide, is built up of one $\frac{3}{4}$ and three $\frac{5}{8}$ plates at centre, reduced to one $\frac{3}{4}$ and two $\frac{5}{8}$ at ends. Each

Digitized by Google

flange is connected to the webs by four angle-irons, $6 \times 6 \times \frac{5}{8}$. The ordinary width of web plates is 3 ft. Five plates at either end of each line of webs are $\frac{5}{8}$ thick, and the intermediate one $\frac{1}{2}$. The vertical joints are connected alternately by a T iron and strip, and two strips; the size of T iron is 6 ft. $\times$ 3 in. $\times \frac{5}{8}$ in. and of the strips, $6 \times \frac{5}{8}$. The T irons are set over the longitudinal angle-irons; but the strips merely butt.

One end of each main girder rests on eight rollers $4\frac{1}{2}$ in. diameter; the bearing and bed plates are of cast-iron 2 in. thick; at the other end a bearing plate, 4 ft. 6 in. $\times$ 3 ft. $\times \frac{3}{4}$ in., is provided, and flush-riveted to under side of girder.

The distance between top flanges of main girders, or, in other words, the clear width of bridge, is 35 ft. 8 in.

The cross girders are 2 ft. deep, but vary in width from 15 in. to 7 in. They are riveted to underside of main girders, 4 ft. apart, centre to centre. The 15 in. girders are attached by sixteen rivets, 1 in. diameter, at each end

In consequence of the great skew of bridge, five cross girders only are attached to both main girders; these are 40 ft. 2 in. long, with top and bottom flanges $15 \times \frac{1}{2}$, each connected to the $\frac{1}{2}$ web by two angle-irons, $4 \times 4 \times \frac{1}{2}$; the webs are stiffened by vertical T irons, which divide the length of girder into seven panels. The roadway is on the second system, shown in Fig. 13.

In this bridge a facia of $\frac{1}{4}$ plate was riveted to vertical angle-irons on ends of cross girders; a flat strip was also riveted to bottom of facia plate.

The weight of both main girders is 90 tons 8 cwt.; of all the cross girders, 55 tons 15 cwt.; and of the whole bridge, 178 tons 5 cwt.

Waterloo-road.—The main line is carried over this road by two girders, each 121 ft. long: they are 11 ft. 8 in. deep at centre, and 9 ft. 10 in. at ends. Both flanges are 2 ft. 6 in. wide; the top is built up of five $\frac{5}{8}$ plates at centre, reduced to three at ends; the bottom is built up of one $\frac{3}{4}$ and four $\frac{5}{8}$ plates at centre, reduced to one $\frac{3}{4}$ and two $\frac{5}{8}$ at ends.

Each flange is connected to the webs by four angle-irons $6 \times 6 \times \frac{5}{8}$. The ordinary width of webs is 3 ft, and the arrangement of vertical joints the same as in the last example: six plates at either end of each line of webs are $\frac{5}{8}$ thick, and the remainder $\frac{1}{2}$.

The clear width of bridge is 40 ft. 6 in., to allow for the curve of line.

The cross girders are riveted to main girders 4 ft. apart, centre to centre; they are 2 ft. deep, with flanges each 15 in. wide, and in two $\frac{1}{2}$-inch thicknesses; two angle-irons, $4 \times 4 \times \frac{1}{2}$, connect each flange to $\frac{1}{2}$ web. To the top flange a plate 19 in. wide $\times \frac{1}{2}$

Digitized by Google

is also riveted for attaching road plates on the third system. Figs. 6 and 8.

One end of each main girder is provided with rollers, as shown in Figs. 11 and 12.

The weight of both main girders is 125 tons 2 cwt.; of all the cross girders 119 tons 8 cwt.; and of the whole bridge 276 tons 15 cwt.

Blackfriars-road.—One of the abutments of this bridge is at right angles to line, and the other only slightly out of square. This and Waterloo branch bridge are the only ones in which all the cross girders are connected to both main girders.

The main box girders, which are 110 ft. long, have a central and end depth of 10 ft. 6 in. and 8 ft. 10 in.: both flanges are 2 ft. 6 in. wide; the top is built up of five $\frac{9}{16}$ plate at centre, reduced to four at ends; the bottom is built up of one $\frac{5}{8}$ and four $\frac{9}{16}$ plates at centre, reduced to one $\frac{5}{8}$ and three $\frac{9}{16}$ at ends. Each flange is connected to the webs by four angle-irons $6 \times 6 \times \frac{9}{16}$: eight in the whole section.

The two end web plates at either end of each line are 2 ft. wide, and the intermediate ones are 3 ft.

The girders are braced internally at seven points by a system of lattice bars, shown in Fig. 1; the bars are $2 \times \frac{3}{8}$, and are riveted to **T** irons, which, in this case, are substituted for the internal strips.

The cross girders, twenty-four in number, have flanges 15 in. wide $\times \frac{1}{2}$ thick, riveted to a $\frac{1}{2}$ web by $4 \times 4 \times \frac{1}{2}$ angle iron: they are 2 ft. deep, and each end is riveted to the main girder with 20-inch rivets; the web is divided by vertical **T** irons into eight panels.

The weight of both main girders is $106\frac{1}{2}$ tons; of all the cross girders, 71 tons 12 cwt.; and of the whole bridge 214 tons 17 cwt.

The roadway is on the second system, Fig. 13.

Southwark-bridge-road.—In this case, the main girders are 135 ft. and 82 ft. long respectively: the cross girders and road plates similar to Blackfriars, excepting, of course, the difference in section of short cross girders for skew ends of bridge.

The dimensions of the 135 ft. girder are as follows:

The depth at centre is 12 ft, and at ends 9 ft. 8 in.: both flanges are 2 ft. 6 in. wide; the top is built up of five $\frac{5}{8}$ plates at centre, reduced to three at ends; the bottom is built up of one $\frac{11}{16}$ and four $\frac{5}{8}$ plates at centre reduced to one $\frac{11}{16}$ and two $\frac{5}{8}$ at ends. Each flange is connected to the webs by four angle-irons $6 \times 6 \times \frac{5}{8}$. The webs and their vertical connexions are similar to those in the Blackfriars-road-bridge. All the vertical rivets are 1 in. and the horizontal $\frac{7}{8}$-in. diameter.

Digitized by Google

The 82 ft. girder has a central and end depth of 9 ft. and 7 ft. 6 in. respectively: each flange is 2 ft. 2 in. wide, and connected to webs by four angle-irons $4 \times 4 \times \frac{1}{2}$; the top is built up of four $\frac{5}{8}$ plates at centre, reduced to three at ends; the bottom is built up of one $\frac{3}{4}$ and three $\frac{5}{8}$ at centre, reduced to one $\frac{3}{4}$ and two $\frac{5}{8}$ at ends. The webs are $\frac{3}{16}$ thick, but the vertical T irons and strips are the same as in other girder.

Both girders are braced internally with lattice bars $2 \times \frac{3}{8}$, as shown in Fig. 13.

The long cross girders, or those connected to both main girders, and the road plating, are the same as in Blackfriars-bridge.

A cast-iron cornice is bolted to ends of cross girders, as shown in Figs. 11 and 13.

The weight of the 135 ft. girder is $68\frac{1}{4}$ tons, of the 82 ft. girder 27 tons 3 cwt., and of the whole bridge, 199 tons.

The next bridge we have to notice is the one over Southwark-street, which, as stated in the introductory sketch, is a structure consisting mainly of two bowstring girders, having riveted and bolted to them cross girders for forming platform.

In Plate 2, Fig. 5, is a half elevation of one side of bridge, and Fig. 6 is a transverse section through A A in Fig. 5.

In Plate 3, Fig. 1, is a transverse section at centre of a girder; Fig. 2 is an elevation of girder at centre strut; and Fig. 3 is a section of struts.

Referring to Plate 2, Fig. 5, it will be seen that each bowstring is composed of four primary members—the bow, the tie, the system of struts, and the system of diagonals: the length over all is 150 ft., and the distance, centre of bow to centre of tie at middle span is 18 ft., and width of both 3 ft.; the bow and tie are two troughs of similar section, the first being inverted, and are constructed thus:

The bottom of the trough is built up of three $\frac{5}{8}$ plates 3 ft. wide, in ordinary lengths of 5 ft. 8 in., breaking joint in the usual way; each side, which is 2 ft. deep, and formed of two $\frac{5}{8}$ plates, is riveted to this bottom by two angle-irons $5 \times 5 \times 1$ in. A reverse angle-iron, as shown in Plate 3, Figs. 1 and 2, is also riveted to sides externally.

The struts, nine in number, may be described as small lattice girders, 1 ft. $7\frac{1}{2}$ in. deep, with equal flanges 8 in. wide $\times \frac{5}{8}$ thick. To each flange two angle-irons $3 \times 3 \times \frac{3}{8}$ are riveted back to back, between which the lattice bars $2\frac{1}{2} \times \frac{1}{2}$ are also riveted. For a length of 18 in. at each end a $\frac{1}{2}$ plate is substituted for the lattice bars. The struts are riveted together with $\frac{5}{8}$ rivets, and to bow and tie with twenty-four 1-inch rivets in each case.

Flat bars 6 in. wide constitute the diagonals: the twelve

Digitized by Google

central pairs are $\frac{3}{4}$ thick, and the remainder $\frac{5}{8}$. Excepting in eight cases, they are connected to bow and tie by gib and cotter. The eight cases referred to are the ends of end diagonals, next ends of girders which are attached by six rivets 1 in. diameter.

In this, as in other structures, the junctions of the various members have required the greatest synthetic skill. The two important cases are, first, the connexion of bow and tie; second, the connexion of bow, tie, struts, and diagonals together. To accomplish the first, the laminated plates and angle-irons of bow are made to butt on those of tie, a small angle-iron corner piece being riveted at junction of angle-irons; the reverse angle-irons of bow and tie butt, and are connected by a **V** shaped joint plate. The space between bow and tie, for a distance of 14 ft. 6 in., is filled in with $\frac{1}{2}$ in. plate, which butts against the extremities of the arms of angle-irons of bow and tie, and extends to end of girder; the vertical joints of this plating are connected by an interior and exterior strip $8 \times \frac{3}{4}$. A front plate is also riveted to this plating by **T** iron $3 \times 3 \times \frac{1}{2}$. The side plates of bow and tie butt, and the joints are covered by the $\frac{1}{2}$ inch plating internally, and a strip $8 \times \frac{3}{4}$ externally.

The junction of bow and tie is further strengthened by a $\frac{1}{2}$ inch plate riveted to bow and tie by angle-iron $5 \times 5 \times 1$, and extending for a distance of 9 ft. from end of girder.

To make the second connexion—namely, that of bow, tie, struts, and diagonals together, a plan was adopted, consisting of first riveting to sides of trough, internally, with countersunk rivets, a plate 2 ft. 8 in. long 2 ft. 3 in. wide, with slot holes at upper corners to correspond with diagonals; the holes corresponding with those in strut are left open. The strut is next introduced, to the inner side of each flange of which are applied two wing plates, with six rivet holes and slot holes, corresponding to those in one half of the first mentioned plate. The whole are then riveted together with twelve rivets 1 in. diameter on each side of strut. The plate next sides of trough and the wing plates are $\frac{3}{4}$ in. thick.

The external side-joint plates of bow and tie, and the vertical and horizontal joint strips at end of girder are all shown in position in Plate 2, Fig. 5.

One end of each girder is placed on eight rollers 6 in. diameter, and provided with bearing and bed plates of cast iron 2 in. thick.

The rivets are all 1 in. diameter and 4 in. pitch, excepting those through $\frac{1}{2}$ in. plating, and $3 \times 3 \times \frac{1}{2}$ angle-iron or joint strips, which are $\frac{7}{8}$ in.

There are thirty-six cross girders; twenty-two of these are box and the remainder single web. Ten cross girders only are

Digitized by Google

connected to both bow strings, which are of the box type; and fourteen out of the twenty-two box are of heavier section than the remainder; but the single web are all one section. The depth of all the cross girders is 3 ft. 3 in.

The width of the strong box girders is 1 ft. 8 in.; the flanges are built up of two ½ in. plates with joint covers, and each riveted to a $\frac{3}{16}$ web by two angle-irons 6½ × 3½ × $\frac{9}{16}$.

In the light box girders the flange plates are ⅜, and the angle-iron 3½ × 3½ × ½.

The box girders are connected to the under side of bow strings by twenty 1 in. rivets, and two 1¼ in. bolts.

A ¼ plate is riveted to top flanges of cross girders for attaching road plates according to the third system, Plate 1, Figs. 6 and 8.

Referring to Plate 2, Fig. 5, it will be seen there is an open work facia. This is formed by bolting a ¼ plate to ends of cross girders; then filling in the spaces with crosses of 3 × ½ iron, and attaching, by countersunk screws, to bottom of ¼ plates, a line of angle-iron 3 × 3 × ⅜.

The weight of each bowstring girder is 117 tons; of all the cross girders 180 tons; and of the whole bridge 458 tons.

The clear width of this bridge is 56 ft., for the reasons stated in introductory sketch.

The next iron structure in order is the section of Borough Market Viaduct from Counter-street to York-street. The bridge over the first street is included.

This section of viaduct is 200 ft. long, in six spans, and built on a curve.

Plate 2 refers to this portion of viaduct, Fig. 1 being a transverse section.

The supporting works are two brick abutments and fifteen cast-iron columns, arranged in sets of three, as shown in Fig. 1. The bearing works are three lines of single web girders, placed immediately over columns, to each of which they are secured by four 1¼ tap bolts. These lines of girders are 12 ft. 6 in. apart, centre to centre; they are braced over columns and abutments with plate bracing; at mid span there are open frames. The outer lines of girders are provided with a parapet 6 ft. high. The viaduct is covered with 9 in. square timber, with hoop iron tongue 1½ × ⅛; and on this timber the longitudinal rail timbers are laid.

From the preceding remarks the general features of the viaduct will be understood. The detailed description will, therefore, be commenced with the columns: these are all 24 ft. high over all; the diameter at base 2 ft. 1 in., and at capital 1 ft. 9 in.; on plan the capital is 2 ft. 9 in. square; and the thickness of metal in inner columns 1½ in., and the outer 1 in.

Digitized by Google

The base of the inner column is 3 ft. 1 in. square, and has holes to suit four $1\frac{1}{2}$-in. holding-down bolts; the outer columns have a projection on the outer side of base, and the angle filled in with a bracket. There are five holding-down bolts. The foundation for columns consists of—first, a bed of concrete; second, a pier of brickwork in cement, 8 ft. 6 in. high, 8 ft. × 6 ft. at bottom, and 6 ft. × 4 ft. at top—these horizontal dimensions are for the outer columns; third, a 6-in. York landing, the same size as top of brick pier, on which the base of column rests.

It may now be considered that the fifteen columns and the two brick abutments are all in place ready for the bearing works—the inner and outer lines of longitudinal girders.

These girders are all of the single web type, 3 ft. high, and are seen in section in Fig. 1; the inner girders for the four centre spans are 32 ft. $3\frac{3}{8}$ in. long; the top and bottom flanges are 16 in. wide, and built up of two $\frac{7}{16}$ plates, with joint covers; the webs are $\frac{1}{4}$ thick, connected to each flange by two angle-irons $4 \times 4 \times \frac{1}{2}$, and stiffened at vertical joints by **T** iron, $5 \times 2\frac{1}{2} \times \frac{3}{8}$.

The outer girders, on the convex side of viaduct, are, for the four centre spans, 32 ft. $5\frac{7}{8}$ in. long, and 3 ft. high; each flange is 16 in. wide, $\frac{3}{8}$ thick, and connected to a $\frac{1}{4}$ web by two angle-irons, $4 \times 4 \times \frac{3}{8}$; the vertical joints of webs are stiffened, the same as inner girders. On the upper side of top flange an angle-iron, $3 \times 3 \times \frac{3}{8}$, is riveted. This is for attaching a sheet-iron parapet, similar to that described for Vine-street Bridge.

The connexion of longitudinal girders to each other, to bracing and to column, is as follows:

To the bottom flanges of the two girders are flush riveted two $\frac{3}{4}$-plates, together being the size of top of column, the joint coinciding with webs, and each having two holes for the $1\frac{1}{4}$-in. top bolts, shown in Fig. 4. The top flanges are connected by $\frac{9}{16}$ joint plate; the webs of inner girders are connected by the plate bracing riveted on each side of them; those of outer by the bracing on one side, and a **T** iron on the other.

The bracing over columns consists of web, angle-iron, and central vertical **T** irons; the webs are $\frac{1}{4}$, angle-iron $3 \times 3 \times \frac{1}{2}$, and **T** iron $5 \times 2\frac{1}{2} \times \frac{3}{8}$.

The open frames are of **T** iron, $5 \times 3 \times \frac{1}{2}$, with diagonal bars of $3\frac{1}{2} \times \frac{1}{2}$; the vertical **T** irons same section as in plate bracing.

The timbers are bolted down by $\frac{7}{8}$ hook bolts. The ends of the longitudinal girders, on brick abutments, have riveted to them bearing plates, 3 ft. × 2 ft. × $\frac{3}{4}$ in.

The weight of cast iron in the viaduct is 54 tons, and the weight of wrought iron 82 tons 4 cwt.

The section of Borough Market viaduct, from York-street to

Digitized by Google

Wellington-street, is in three spans of 45 ft. each; the supporting members are two brick abutments, and two piers of cast-iron columns; there are five columns in one pier, and four in the other, which are the same as those in the other section of viaduct.

On plan, this section is of a "Fan" shape, being 37 ft. wide at one end, and 62 ft. 6 in. at the other; this width is due, as before noticed, to the viaduct being the site of the Eastern Junction of City Extension.

Each row of columns is surmounted by a box girder, 2 ft. wide and 1 ft. 6 in. deep, which forms the bed for the longitudinal girders, and is riveted thereto; tap bolts secure the box girders to top of columns.

There are in all 24 longitudinal girders, arranged thus: in the opening next York-street, 9; in the centre opening, 8; and in the one next Wellington-street, 7. These girders are all 4 ft. deep, and, with the exception of the two face ones, in each opening, are all placed parallel with each other. Each of these face girders splay more or less with the inner one of the same opening next it; and in four cases cross girders are filled in between them, for that portion of length, in which the distance centre to centre exceeds 4 ft. The distance centre to centre of the cross girders is 4 ft.

On the top of the longitudinal girders 6-in. plank is laid; it is transverse to these girders, excepting at those points where the cross girders are introduced.

Five of the girders in the opening next York-street are 51 ft. span; the flanges of these are 16 in. wide, and built up of two $\frac{1}{2}$-in. plates, with joint covers; the webs are $\frac{1}{4}$ thick, and connected to flanges by angle-iron, $4 \times 4 \times \frac{5}{8}$. Seventeen of the girders have flanges 16 in. wide by $\frac{3}{4}$ in. thick, also connected to a $\frac{1}{4}$ web by $4 \times 4 \times \frac{5}{8}$ angle iron. For the remaining two, the flanges are $16 \times \frac{3}{8}$, and the angle-iron $3 \times 3 \times \frac{3}{8}$. In all cases the webs being in about 5 ft. sections.

The longest cross girder is 19 ft.; it is 16 in. deep, and consists of a $\frac{1}{4}$ web, with two angle-irons $3 \times 3 \times \frac{1}{2}$, top and bottom for flanges. The shortest cross girder is 6 ft.; it is 12 in. deep, with flanges of $2\frac{1}{2} \times 2\frac{1}{2} \times \frac{1}{2}$ angle-iron.

The bracing, the connexion of top flanges of girders, and parapet, are all similar to those in the other section of viaduct.

The weight of columns is 40 tons; of the two box girders, 11 tons 2 cwt.; of the longitudinal girder, 129 tons 18 cwt.; and of the whole viaduct, 201 tons.

With reference to St. Thomas's viaduct, it is only necessary to say that the girders, mentioned in the introductory sketch, vary in length from 41 ft. 4 in. to 19 ft. 8 in. for one opening; and

Digitized by Google

from 48 ft. to 25 ft. for the other. They are of the single web type, 2 ft. 6 in. deep, braced together by diagonal bars, $3 \times \frac{5}{8}$, and covered with 8 in. planking. The weight is 28 tons.

The only bridge remaining to be described is that over the incline to the South-Eastern Station. In this the bearing works are two elliptical box girders, 207 ft. and 176 ft. long respectively.

Plate 2, Fig. 7, is a centre section of the 207 ft. girder.

The platform of bridge is formed by eighty cross girders, with road plating on the third system. Plate 1, Figs. 6 and 8. Of these eighty girders, thirty-one only are connected to both mains. The longest of these is 50 ft. 4 in., and the shortest 44 ft.; the depths of cross girders vary from 1 ft. 6 in. to 9 in. These will be referred to again.

Returning to the main girders, it is proposed to describe fully the 207 ft. girder, and then to point out wherein the 176 ft. differs from it.

Since the order in which any structure is built is the best to describe it in, it will be followed in this case.

The bottom table is 3 ft. wide, and is built up of one $\frac{9}{16}$ in. and four full $\frac{1}{2}$ in. plates. These plates are riveted to each other and to four lines of angle-irons, $6 \times 6 \times 1$, by five longitudinal lines of rivets 1 in. diameter.

The angle-irons are in pairs, back to back, the space between the vertical arms being such as to admit the web plate, with a $\frac{3}{4}$ in. side plate on each side of it (the web); the side plates are 18 in. deep, and all the rivets through them are 1 in. diameter.

The distance between webs at centre of girder is 1 ft. 10 in. They are in 3 ft. widths, and, with the exception of the three at either end, are in two sections, vertically, the joint being made by two horizontal strips, $6 \times \frac{3}{8}$. The three webs at either end of a line are $\frac{1}{2}$ in; the next five, at either end, $\frac{3}{8}$; and the intermediate ones, $\frac{1}{4}$. Extra webs, $\frac{1}{2}$ in. thick, are added at either end of each line, for a distance of 15 ft.

The vertical joints of webs are connected by a tee iron, $6 \times 3 \times \frac{3}{8}$, and a strip, $6 \times \frac{3}{8}$—the tee iron external. Both are made to set over side plates and angle-iron. The girder is braced internally by eleven diaphragms about 18 ft. apart. They are formed of $\frac{1}{2}$ plate and $3 \times 3 \times \frac{1}{2}$ angle, and are seen in section, and in position in Plate 2, Fig. 7.

The partially built girder may now be supposed standing with bottom table and webs in position, ready for receiving the top table, which is similar in section to the bottom. This is done as follows:

Into the space which the cranked ends of vertical tee irons and strips form with the web, the side plates, 1 ft. 6 in. deep $\times \frac{3}{4}$ thick, are introduced; then into the space which the side plates make with the shorter crank, the longitudinal angle-irons, $6 \times 6 \times 1$, are

Digitized by Google

placed. This done, the girder is ready for receiving the top laminated plates; these are 3 ft. wide, six in number, and full $\frac{1}{2}$ in. thick.

All the rivets in top table, from lower edge of side plates upward, are 1 in. diameter; the rivets through vertical strips are $\frac{3}{4}$ in. diameter. The pitch of rivets throughout is 4 in.

Under one end of the girder, twelve rollers, 6 in. diameter, are placed, with bearing plates and bed plate of cast iron 3 in. thick.

The ordinary length of the angle-iron bars is 18 ft.; the joint covers for bottom table are 4 ft. and those for the top table 2 ft. long.

The side plates are in 9 ft. lengths, and the joint plates for them are 2 ft. 6 in. × 1 ft. Since the distance centre to centre vertical tee irons is 3 ft., and their width 6 in., it will be seen that these joint plates just fit in between the tee irons.

The ordinary length of the laminated plates is 6 ft. 8 in.

The 176 ft. girder being so similar to the one just described, it is considered only necessary to give the dimensions of those elements which differ. These are as follows: The laminated portion of the top table is built up of five $\frac{3}{8}$ plates, and of the bottom of four $\frac{1}{2}$ in. plates. The side plates are $\frac{1}{2}$ in. thick, and in 15 ft. lengths.

As previously stated, more particulars will now be given of the cross girders. There are seven different sections: the dimensions of the strongest are: Depth, 18 in.; flanges, 12 in. wide, built up of two $\frac{3}{4}$ plates, with joint plate; web, $\frac{1}{4}$ in.; angle-iron, $5 \times 4 \times \frac{3}{4}$. The dimensions of the lightest are: Depth, 9 in.; web, $\frac{1}{4}$ in., with flanges, each formed of two angle-irons, $4 \times 3\frac{1}{2} \times \frac{5}{8}$.

All the cross girders above 9 in. in depth, are reduced to that depth, at those ends which are bolted to main girders; and a cast-iron cornice is bolted to them, similar to that shown in Plate 1, Figs. 6 and 13.

The cross girders, in this case, are bolted to main girders; the girders, 12 in. wide, are each connected to the 207 ft. girder with fourteen bolts 1 in. diameter, and to the 176 ft. by thirteen; in all the other cases there are ten. These bolts are long enough to pass through both flanges, the head of bolt bearing against bottom flange or plate riveted thereto.

The curve of line on this bridge is to about a ten chain radius. The longitudinal timbers for higher rail are two 12 × 9 bolted together, and for the lower rail two 12 × 6.

The line is also on a gradient; the difference of level between the ends of the 207 ft. girder being 12 in.

The weights are:

207 ft. girder . .	191 tons	17 cwt.	
176 ft. " . .	134 "	12 "	
Heaviest cross girder .	5 "	15 "	
All " .	267 "	10 "	
Whole bridge . .	617 "	17	

Digitized by Google

In conclusion, it is only thought necessary to say that, in all cases, the "rolling load" was taken at 1¼ tons per foot forward of single line; maximum strains in compression and extension, 4 tons and 5 tons respectively per square inch.

The deflections of the various bridges, as on diagram, are produced by a load of one ton per foot run of single line.

CHARING-CROSS RAILWAY: Road-bridges—Deflections of Wrought Iron Girders.

NAME OF BRIDGE.	Length of Girders in Clear.		Width of Bridge.		Lines of Way.	Distributed Load in Tons.	Deflections at Centre.
	ft.	in.	ft.	in.	No.	tons.	in.
Joiner-street Bridge ... Main girder	60	0	...		...	108	.66
" " ... "	44	0	45	0	3	78	
Approach Bridge ...... "	185	0	...		...	255	.84
" " ...... "	156	0	43	0	3	210	.63
Wellington-street Bridge.................. "	118	0	...		...	156	.78
" " ...... "	118	0	36	6	3	156	.72
Borough Market Viaduct............ Longl. girds.	46	3	...		...	23	.24
	47	6	38	0	3	23	.24
	46	4	...		...	23	.18
York-street Bridge... "	36	0	25	0	2	18	.30
Borough Market Viaduct .... "	31	6	...		...	20	.24
	32	0	...		...	21	.24
	32	0	25	0	2	21	.30
	32	0	...		...	21	.36
	32	0	...		...	21	.30
	40	0	...		...	26	.42
Southwark-street Bridge . Main gird.	130	0	...		...	220	.42
" " "	130	0	56	0	4	This girder not tested.	
Southwark-road Bridge... "	121	0	...		...	172	.54
" " "	73	0	35	8	3	110	.36
Blackfriars-road Bridge... "	100	0	...		...	150	.60
" " "	100	0	35	8	3	150	.48
Broadwall Bridge ......Longl. girds.	41	0	35	8	3	20	.24
Waterloo Branch Bridge . Main gird.	76	0	...		...	55	.36
" " ...... "	76	0	26	6	1	21	.18
John-street Bridge ...... "	75	0	...		...	60	.24
" " ...... "	72	0	35	8	3	55	.24
Waterloo-road Bridge ... "	110	0	...		...	150	.48
" " ... "	110	0	41	0	3	150	.36
Vine-street Bridge......Longl. girds.	48	0	35	8	3	24	.30
York-road Bridge.........Main girds.	70	0	...		...	100	.48
" " .... "	70	0	35	8	3	100	.48
Sutton-street Bridge ... "	90	0	...		...	135	.36
" " ... "	90	0	35	8	...	135	.36
Belvedere-road Bridge .. Longl. gird.	46	0	35	8	3	23	.24

The engineer for the line was Mr. J. Hawkshaw, and the

Digitized by Google

whole of the ironwork was executed by Messrs. Cochrane, Grove, and Co., of Dudley.

APPENDIX.—Table of Dimensions, &c.

	Top Flange.	Bottom Flange.	Span.	Depth.	$\frac{l}{8d}$	Load.	Strn. at Cen.	Weights.	
								Total.	Main Gird.
	sq. in.	sq. in.	ft. in.	ft. in.		tons.	tons.	tons.	tons.
Broadwall	22.87	18.15	41 0	2 6	2.05	31	63½	43	4¼
York-road	65.6	51.05	74 0	7 3	1.28	202	258½	141¾	25
John-street	57.35	47.35	88 1	6 9	1.63	124	202	124½	24½
Waterloo Branch	61.85	51.05	77 9	6 3	1.55	146	226¼	94	24½
Wellington-st....	104.8	81.5	124 3	11 8	1.33	328	436	248	65
Joiner-street ...	82.0	67.6	61 3	5 2	1.48	202	299	115¾	21½
Sutton-street ...	80.9	64.55	103 3	7 5	1.75	195	341¼	178¼	45¼
Waterloo Main..	103.4	85.4	111 9	11 4	1.23	332	408¼	276¾	62½
Blackfriars-road.	93.2	77.0	100 9	10 3	1.23	303	372½	214¾	53
Southwark-road									
135 ft.	103.4	85.4	125 9	11 8	1.34	299	400	199	68¼
„ 82 ft.	63.75	52.05		8 8	...	...	...		27¼
Southwark-st. ...	159.0	134.0	140 0	18 9	.93	555	516	458	117
Approach .207 ft.	188.0	138.0	195 0	18 2	1.34	642	860¼	618	192
„ 176 ft.	134.0	109.0		18 2		664	890		134¾

DISCUSSION.

Mr. ZERAH COLBURN expected Mr. Parkes would have said more about the Charing-Cross Bridge, it being the principal feature of the line. The paper, however, contained a great deal of most valuable information, but it was a paper which would be much more appreciated when read over and reflected upon, than it possibly could be by being listened to when read. Sections of the top and bottom flanges had been given, but without the loads and limits of strain. It appeared that in the plate bridges the holes had been drilled and not punched. It was very important that a discussion should arise upon the comparative strength of drilling and punching. At present there was a great difference of opinion; there were only a few firms which drilled their rivet holes, most firms punched them. When he (Mr. Colburn) visited Mr. Fairbairn's works at Manchester, he found they did not agree with drilling holes, believing it to be more expensive without adding to the strength. He (Mr. Colburn) believed that the bridges of the Charing-Cross line were among the first in the kingdom, in which all the rivet holes were drilled instead of being punched. His opinion had always been, that there was a decided advantage in it, and that the mere operation of punching injured the iron considerably; he thought Mr. Fairbairn's own experiments went to show that.

Digitized by Google

Mr. PARKES explained that the rivet holes in all the bridges were not drilled—only those in the Thames Bridge.

Mr. LE FEUVRE said the society were much indebted to Mr. Parkes for the paper he had produced. The details had been gone into so minutely that it required time for reflection before the several subjects introduced could be described. There was no doubt that in this line the engineer had a number of difficulties and circumstances which no engineer ever before had to deal with, and, moreover, the engineer had had to adapt his constructions to the situation. The system of bridges adopted was very good—viz. dividing them into single web, bow, and box girders. In small spans no doubt the single web answered well, in the larger spans the box girders, and in the largest spans the bow and truss girders. Hanging the cross girders he thought most objectionable. Cross girders ought to be placed instead of under the bottom flange, on the upper side of the main girder. He had understood that the distances between the cross girders varied in some of the bridges. He thought cross girders in a bridge ought to be equally distant apart. The engineer had not succeeded in making the bridges water-tight. It was, no doubt, a difficult thing to make a bridge water-tight, but he thought it should be compulsory to make all bridges water-tight. There could be no question that the details of these bridges had been carefully and well carried out. He agreed with Mr. Colburn that there were great advantages in drilling the holes in all the bridges; he thought several of the bridges ought to have been made of larger spans, so as to allow at any future time for widening the streets. The bridges constructed in London were not of sufficient width between the abutments on which the main girders of the bridge rested. As regarded the rollers, he thought they were of little use, he thought rubbing plates would be quite sufficient. The cross girders were close up to the abutments, and he did not know whether there was sufficient play for the rollers. As regarded the approach bridge to the London Bridge Station, he did not think the engineer had been very successful in an architectural point of view. In fact, so utterly deficient was it of anything like architectural beauty, that this bridge had been the cause of the Metropolitan Board of Works making it imperative that in all railway bills a clause should be inserted that all the designs of bridges should first have the approval of that board before being erected. He thought this was a very judicious step, although it might incur considerable expense. As a rule, engineers were not very successful as architects. As regarded the Charing-Cross bridge, every one admitted that the bridge was most admirably designed. It was an enormous bridge, and necessarily required to be very strong and of peculiar construction.

Digitized by Google

17*th October*, 1864.

R. M. ORDISH IN THE CHAIR.

THE WROUGHT IRON ROAD BRIDGES OF THE CHARING-CROSS RAILWAY.

By M. Parkes.

ADJOURNED DISCUSSION.

It having been remarked by Mr. Colburn at the last meeting of the society, on the 3rd inst., that the chief feature of the Charing-Cross Railway was the Hungerford Bridge, the writer now endeavours to place before the meeting a few more particulars of it. The writer's object in keeping simply to the road bridges was to avoid bringing before the society a paper containing, as it necessarily must have done, a quantity of information already published. The writer refers to the valuable and comprehensive paper by Mr. Harrison Hayter (Mem. Inst., C.E.), read before the Institution of Civil Engineers, April 28, 1863. Since our last meeting the writer has carefully read over the paper referred to, as it appeared in the *Engineer* of May 1, 1863, and finds the matter so fully dealt with as to make supererogatory anything he might say. However, as the writer promised to open the discussion this evening, he thinks he cannot do better than to confine his attention chiefly to a minute description of the main girders of the 154 ft. spans, and the method of suspending the cross girders thereto.

The main girders just referred to, may be described as wrought iron "lattice" girders. They each consist of a top and bottom horizontal member, 4 ft. and 3 ft. wide respectively, two vertical end pillars, and two systems of diagonal struts and ties, the whole being connected together with pins of puddled steel. One of the systems of struts and ties forms with the lower horizontal member a series of seven triangles, and the other system does the same with the top member. It will thus be seen there are fifteen pins in each member, the length of the girder over all at top being 164 ft. The distance between centre to centre of pin-holes of bottom is 10 ft. 11$\frac{9}{12}$ in., thus making the distance between centre to centre end pin holes 153 ft. 9$\frac{2}{3}$ in., the length of bottom over all being 163 ft. 9$\frac{2}{3}$ in. The struts and ties being all one length centre to centre of pin holes, and the distance between centres of pin holes at bottom being, as stated, $\frac{2}{12}$ths of an inch less than those at top, produces a camber of 4 in. at centre of girder. The depths of girder are:—total depth at

Digitized by Google

centre 14 ft. $4\frac{3}{8}$ in.; depth between centres of gravity of top and bottom 13 ft.; centre to centre pin holes 11 ft. 6 in. The top and bottom members each consist of a horizontal table and four vertical ribs; these ribs are bored to receive the puddled steel pins. The sizes of the upper and lower pins are the same, and of the following dimensions: the two end 7 in. diameter; the next two at either end $6\frac{1}{2}$ in.; the next two at either end 6 in.; and the five central ones 5 in. diameter. It is proposed now to describe the construction of each member. The horizontal table of the bottom is 3 ft. wide, and built up of 160 plates. There are six layers, a centre one $\frac{11}{16}$ and five $\frac{5}{8}$, reduced to two at ends, one $\frac{11}{16}$ and one $\frac{5}{8}$. Each layer of plate is in two widths; the upper one in two 18 in. widths, and the remainder in 12 in. and 24 in., so that they break joint transversely. The length of overlap in a longitudinal direction is 16 in. The ordinary length of the plates is 7 ft. 11.88 in. These plates are all riveted to one another and to four lines of angle iron, by six rows of 1 in. rivets. The angle-irons, which are $6 \times 6 \times 1$ in. at centre, reduced to $6 \times 6 \times \frac{3}{4}$ at ends, are all placed with the horizontal arms inwards, or towards the centre of the girder. The holes are so arranged that between the backs of the two outside lines of angle and the edge of the horizontal table, there is a ledge $1\frac{1}{8}$ wide at centre of girder. This is to admit of the vertical ribs being flush with the edges of the horizontal table. The two central lines of rivet holes are so arranged that the distance between the two inside vertical ribs is 13 in. The angle covers are 4 ft. long 5×5 in. $\times$ 37 lb. per foot.

To the four lines of angle-iron the vertical ribs are riveted with $\frac{7}{8}$ rivets. The two outside ribs are 24 in. deep, and each consist of a $\frac{5}{8}$ in. and $\frac{1}{2}$ in. plate at centre, reduced to two $\frac{3}{8}$ in. at ends. The ordinary length of these plates is 10 ft. $11\frac{19}{32}$ in., and they break joint at the pin holes. The joint plates are 2 ft. 4 in. long, the outer one 24 in., and the inner 18 in. deep, the thickness is one inch, so as to give a good bearing surface for the pins. The two inner ribs are 21 in. deep, and each consist of two $\frac{5}{8}$ plates at centre, reduced to two $\frac{3}{8}$ at ends. In addition to these an extra length of plate, 15 in. deep $\times$ $\frac{5}{8}$ in. thick, extends sufficiently to contain the five 5 in. pin holes: this plating is on the inner side of the ribs. The lengths of plates, sizes of joint plates, &c., are similar to those for the outer ribs, excepting the difference due to the lesser depth. From what has been said it will be seen that the horizontal table with the four vertical ribs form three troughs, the two side troughs being occupied by the struts and ties.

The horizontal table of the top member is 4 ft. wide, built up of 182 plates, all $\frac{5}{8}$ thick. There are five layers of plates at centre

Digitized by Google

of girder, reduced to two at ends; these layers, like those for bottom, are in two widths; the lower layer is in two equal widths of 2 ft., and the remainder are 1 ft. 5 in. and 2 ft. 7 in., thus breaking joint transversely. The ordinary length of the plates is 6 ft. 8 in., and the overlap in a longitudinal direction 16 in. This horizontal table is riveted together, and to four lines of angle-iron by six rows of 1-in. rivets; these angle-irons are placed with the horizontal arm towards the edge of the table. The ordinary length of a bar is 11 ft., and of an angle cover 2 ft.; in other respects they are similar to those in bottom. The holes are so arranged that the distance between the backs of the exterior angle-irons is 2 ft. $10\frac{1}{2}$ in., and between the backs of the interior 1 ft. 2 in.

The plates composing the vertical ribs are in 11 ft. lengths; the joint plates, mode of breaking joint, and depths of plates, being similar to the bottom. Each of the outer ribs consists of two $\frac{5}{8}$ plates at centre, reduced to two $\frac{3}{8}$ at ends; each of the inner consists also of two $\frac{5}{8}$ at centre, reduced to two $\frac{3}{8}$ at ends.

The end pillars will now be described. These are 13 ft. $9\frac{1}{2}$ in. high, 5 ft. $2\frac{3}{4}$ in. long, 2 ft. $10\frac{1}{2}$ in. wide at bottom, and 2 ft. 9 in. at top; the sides, back and front, are all of $\frac{3}{8}$ boiler plate; internally the pillar is divided into three compartments, by diaphragms $\frac{1}{4}$ in. thick. Each side is in two sections vertically, and three sections horizontally; the vertical joints are covered externally by strips, $6 \times \frac{3}{4}$, and internally by T iron, $5 \times 3 \times \frac{1}{2}$, to which the $\frac{1}{4}$ diaphragms are riveted. The front and back are connected to the sides by angle-iron, $3\frac{1}{2} \times 3\frac{1}{2} \times \frac{1}{2}$. The end pillars are riveted together with $\frac{3}{4}$-rivets.

Diagonal struts and ties: Each strut consists of two links in one solid forging; these links are bored at each end to suit the pins, and are united firmly together by zig-zag bracing of bar iron, $4\frac{1}{2} \times \frac{3}{4}$, four cast-iron distance tubes, and four bolts, $1\frac{1}{8}$ in. diameter; the bolts, of course, pass through the distance tubes, and when screwed tightly up, make each strut a rigid framework. The links composing a strut are 12 in. $\times$ 3 in. at the ends of the girder, and 6 in. $\times$ $2\frac{1}{2}$ in. at the centre.

The diagonal ties, like the struts, each consist of a pair of links, and each link consists of two or three separate links riveted together; these links are Howard's suspension links. Each link of a tie is 12 in. $\times$ $2\frac{1}{2}$ in. at ends of girder, and 6 in. $\times$ 2 in. at centre. In consequence of the central diagonals having to act as both struts and ties, the two pairs meeting at the lower central 5-in. pin are constructed similarly to the struts. The diagonals are all bolted together at their intersections; the bolts are 1 in. diameter, with ornamental nuts of cast iron. The ties and struts were all sent to the works, bored to the finished size; but the

Digitized by Google

plates composing the vertical ribs were sent bored out half an inch less than the finished size. The riveting being completed, with the exception of fourteen holes at each pin-hole joint, the vertical ribs were then bored out by means of a boring bar, fitted with two cutters, and working in two cast-iron bearings, bolted to the outer vertical ribs with four bolts. It was for this purpose four of the holes in each pin joint were left open, the remaining ten are for the angle-irons, for attaching cross girders. The boring bar was driven through a counter shaft by a small steam engine, fitted with small flanged wheels, which run on the exterior vertical bottom ribs; by this means the engine could be moved to any part of the girder with facility. The pins were driven home with a ram, which consisted of a pin in its rough state, fitted with the necessary appliances for working it.

The pins were made long enough to project about $1\frac{1}{2}$ in. beyond the outer vertical ribs on either side of girder. This is to accommodate the vertical links, which thus divide the girder into fourteen nearly rectangular spaces, as seen in side elevation. The links are 7 in. × 1 in. at ends of girder, reduced to 6 in. × 1 in. at centre. In both top and bottom straps of 3 in. × $\frac{5}{8}$ in. iron were riveted to both the inner and outer vertical ribs; there are two of these straps between any two pins.

Cross girders: These are on the lattice principle, 54 ft. long, 4 ft. deep at centre, and 2 ft. $1\frac{1}{2}$ in. at ends; they consist of a top and bottom flange, each 18 in. wide and in two $\frac{5}{8}$ thicknesses, united together by lattice bars and angle-irons. Two lines of angle-iron are riveted to each flange, back to back, and 1 in. apart. The lattice bars, sloping one way on either side of centre, are 1 in., and the others $\frac{1}{2}$ in. thick; they vary in width, from 4 in. at the centre to 6 in. at the ends. The 1 in. lattice bars are riveted between the angle-iron and the $\frac{1}{2}$ in. external to them. At each end of the cross girder a lattice cantilever is riveted, it is 7 ft. 3 in. long, 2 ft. $1\frac{1}{2}$ in. deep, where it joins the cross girder tapering to 1 ft. 2 in. at the ends; each flange consists of two angle-irons, $3\frac{1}{2} \times 3\frac{1}{2} \times \frac{1}{2}$, united together by lattice bars, $2 \times \frac{3}{4}$ and $2 \times \frac{3}{8}$, similarly to the cross girders. At the sides of the footpaths is a cast-iron railing, and the ends of the cantilevers are screened by a cast-iron cornice. The deflection of a cross girder with a load of 70 tons was 1 in., and the permanent set $\frac{1}{4}$ in.

Method of attaching cross to main girders: To either side of bottom of main girders, and on either side of the pin holes, an angle-iron $4 \times 4 \times \frac{3}{4}$ is riveted; these angle-irons extend 2 ft. 6 in. below the under side of girder in the case of the inner, the outer being 4 in. less. From what has been said, it will be seen there are four angle-irons at each pin. The cross girder fits between these angle-irons, similar to the axle box in the horn plates of a

Digitized by Google

railway carriage. To secure the cross girders to these angle-irons, a wrought-iron plate 5 ft. 7 in. long, and ½ in. thick, is attached to each end and on both sides, by means of reverse angle-irons on top and bottom flanges. Each angle-iron is secured to the main girders with five rivets, and to the cross girder with seven and six, in the case of the inner and outer respectively.

Each main girder is designed to support a maximum distributed load of 750 tons; this weight produces a strain in the upper and lower members of 1111 tons, which is resisted by 276.5 square inches of section, and 211.75 square inches respectively.

Remarks on the distribution of metal in one of the main trusses (154 ft. span), the "maximum load" and "central strain" on truss due to it, and the pressure on foundations:

Distribution of metal in one main truss:

	Tons.	Cwt.	Qrs.
Top chord	70	4	2
Bottom do.	67	15	2
End pillars	6	0	0
Bracing	46	0	0
Total . . .	190	0	0

Rolling load on one main girder, obtained thus: N.B. rolling load 1¼ tons per foot of single line:

	Tons.
Rolling load 156 ft. × 2½ tons	390
Main truss, deducting end pillars	184
Cross girders and cantilevers	67
Rails	7
Timber in planking and longitudinals	41
Load on footpath taken at 120 lb. per foot sup. .	58

The above load is exclusive of cornice, hand rail, fish plates, bolts, spikes, and chairs for rails, hoop-iron tongue, and bolts for planking.

Pressure on foundation:

From Trinity high water mark to underside main trusses is 29 ft., which, added to the rise of tide, 17½ ft. (say 18 ft.), gives 47 ft. Since brickwork weighs 1 cwt. per foot cube, we have a pressure on top of cone, due to brickwork only, of 2 tons 7 cwt. per sup. foot.

First take the load on main truss, including its own weight as 750 tons, and the diameter of the brick cylinder at 9 ft. 9 in., thus:

Digitized by Google

		Tons.	Cwt.
$\frac{\text{Load} \quad 750 \text{ tons}}{\text{Area 9 ft. 9 in.} = 74.66 \text{ sq. ft.}}$	= . . .	10	0
Pressure due to brickwork		2	7
Total pressure per sq. ft. at top of cone		12	7

Taking cylinders at 10 ft. diameter:

		Tons.	Cwt.
$\frac{\text{Load} \quad 750 \text{ tons}}{\text{Area 10 ft. dia.} \quad 78.54}$	=	9	11
Pressure from brickwork		2	7
Total pressure per sq. ft. on top of cone		11	18

Central strain on one main truss, 154 ft. span, with a maximum distributed load of 750 tons, including its own weight.

Assuming the distance between the centres of gravity of the upper and lower chords to be 13 ft. (which was the result of calculations made by Mr. Parkes), the central strain on one main truss will be 1.111 tons. This number, divided by 4 or 5, will give the required sectional areas of top and bottom chords, respectively, as follows:

	Sq. in.
$\frac{1.111}{4}$ = required section of top = ...	277.7
Actual section = ...	276.5
Deficiency	1.2

	Sq. in.
$\frac{1.111}{5}$ = required section of bottom = .	222.2
Actual section	211.75
Deficiency	10.45

There are 16,052 rivets in each 154 ft. truss.

	£	s.	d.
The cost of the whole bridge . .	180,000	0	0
„ per sq. ft.	1	15	0
„ per lin. ft.	131	0	0

The cylinders for the 154-ft. spans cost 20*l.* per foot lin.; the outer and inner cylinders for the fan end, 12*l.* and 10*l.* respectively.

Digitized by Google

One of the cylinders for the 154-ft. spans sunk permanently 4 inches with 700 tons, and one 3 inches with 450 tons.

Mr. Carrington said, great praise was certainly due to Mr. Parkes for the time and attention he had given to his really valuable paper. The paper was an excellent record of the wrought iron bridges executed on the Charing-Cross Railway, and would add much to the value of the Society's papers, especially when a description of the Thames bridge at Charing-Cross had been added.

It appeared curious, in looking at all these bridges, that there should be so many different designs. Of course a small span required a different design to a large span, but it certainly did not appear to be correct to have bow-string girders for a span smaller than for plate girders. If an open webbed girder was good and proper for a given span, most certainly an open webbed girder was better for a larger span than a plate girder, or close webbed girder. Over the new street in the Borough, the bow-string bridge seemed nearly the proper thing, for the span was large, and required an open webbed girder, both for appearance and economy. All spans over 80 ft. required open webs; they were less costly, and certainly had a much lighter appearance than close webbed plate girders. Yet, strange as it might appear, an ugly plate girder was adopted over the approach to London Bridge Station, and over a span larger than for the bow-string. Why this was, he could not understand.

From what he remembered, there were six distinct species of girders in those bridges.

1st. The single webbed plate girder.

2nd. The double webbed, or box plate girder.

3rd. The bow-string girder.

4th. The bow-string made into a box bow-string plate girder by having a double web instead of struts and ties.

5th. The main girders of the Thames bridge.

6th. The cross girders of ditto, which were lattice girders.

Why there should be so many kinds of girders, he could not quite understand, for they did not appear to be arranged in all cases according to the spans of the bridges. That was, plate girders appeared to be put where lattice or open web girders ought to be.

The pitch, or distance from centre to centre of cross girders in the Thames bridge was 11 ft., and the pitch of cross girders on the other bridges varied from 3 ft. to 4 ft. Why there should be that great difference in pitch was not at all clear. It would appear that the distance from centre to centre of the driving wheels of the locomotive would have something to do with deciding the pitch of the cross girders. Suppose 7 ft. to be

Digitized by Google

about the distance apart of the driving wheels, then 5 ft. or 6 ft. would apparently be more nearly the correct distance (and therefore the most economical) of the cross girders. If the distance was greater than 6 ft., it was advisable to put in wrought iron longitudinal bearers under each rail, so as to complete the proper framework of the bridge in iron. The new railway bridge at Blackfriars was a good specimen of framing for the roadway of a bridge. In the roadway of the Charing-Cross bridge, there were longitudinal timbers 15 in. × 15 in. under each rail, and those timbers had to carry a distance of 11 ft. It certainly appeared more advisable to put a light wrought-iron girder in the place of those timbers, so as to make a complete iron bridge, and not one partly of iron and partly of wood. If in making a railway generally, one or more bridges of 11 ft. or 12 ft. span occurred, it would not be advisable to carry over on balks of timber; either wrought or cast-iron girders would be used, or an arch. Therefore, why should timber be used for 11 ft. spans on such a line as the Charing-Cross Railway?

It was a waste of material to put the cross girders too close together. No matter how near together or how far apart up to about 6 ft., the cross girders must be the same strength, for each one must be calculated to carry the driving wheels of a locomotive, and up to 6 ft. apart, a greater load could not be put on; therefore, if cross girders were only 3 ft. apart, there were twice as many as necessary, and this useless addition added to the weight of the bridge, not only in themselves, but also in increasing the weight of metal in the main girders to carry that extra load.

Much has been said as to the danger of the cross girders leaving the main girders when suspended from the under-side of the bottom flange. That method of fixing did not appear, at the first glance, to be proportionately strong to the strength of the girders; but a little calculation would show that such a connexion is not always the weakest part. Taking a cross girder on the Thames bridge, at the junction with the under side of the main girder, there were four vertical angle-irons, each angle-iron laying hold of the cross girder with about seven rivets, $\frac{7}{8}$ diameter, making a total of twenty-eight rivets, each 6 in. in sectional area, giving a total shearing area of 16.8 square inches. Two of these cross girders were tested with a load of 140 tons, equal to 70 tons on each girder, equal to 35 tons at each end, tending to shear the 16.8 square inches of rivets. That would give a little over 2 tons per square inch shearing strain on the rivets, which must be allowed to be ample for safety. Still cross girders, as a rule, do not look well when suspended from the under side of the main girders, and whenever it is possible,

Digitized by Google

they ought to rest on the bottom flange close to the web. If such arrangement had been adopted on these bridges, there would have been no necessity to cover the ends with a heavy cast-iron cornice, which only added to the weight and expense of the bridge.

There was no doubt that drilled holes in wrought-iron plates decreased the strength of the metal less than punched holes; the metal on the circumference of the holes must certainly be much less injured, and therefore leave more strength in the plate. It was more expensive to drill holes than to punch them; but if by drilling, say ten per cent of the strength of the remaining metal was saved, was it not worth the extra cost of drilling?

If the punching was badly done the metal was injured considerably, but in order to ensure the least possible injury to the metal by punching, the punch must fit the die fairly, and the edges of both must be sharp and clean, which was not always the case; great care ought to be taken to ensure clean sharp edges to the punch and die. Such attention was but seldom given, and the result was that in many cases the holes were half punched and half drifted, much to the injury of the remaining metal in the bar.

There could be no doubt that if the top flange plates were curved transversely they were in a much better form for resisting compression, but the curving of the plates added to the expense of making; it was, therefore, cheaper to add angle-irons on the outside edge so as to give it a good form for compression. That did equally as well, or better, than curving the top plate, was very cheap, for no extra metal was required, and gave a capital form for compression.

In curving longitudinally the top flanges of wrought-iron girders, the expense of the manufacture was increased and but little metal saved; it was, therefore, generally cheaper to keep the two flanges parallel, and avoid adding to the work and difficulty in putting the plates and angle-irons together. He considered that all the bridges were amply strong for the work they had to do, and they were certainly not weak for want of metal.

Mr. Frederic C. Reynolds, referring to diagram No. 7, said he believed it represented a bow and string bridge, but before he proceeded further he would be glad to be informed whether it were a bow and string bridge in the true sense of the term. By a bow and string bridge he understood a bridge formed of girders, in which the top member was composed of a column capable of supporting compression, and of such shape that it should contain within it, or nearly so, the curve of equilibrium due to the weight upon it. This top member should in fact constitute an arch, differing from an ordinary arch in the

Digitized by Google

fact that instead of the horizontal strains being taken by the abutments they should be resisted by a tie rod or bottom member. He (Mr. Reynolds) had no doubt the bridge in question was a well-designed bridge of its kind, and capable of supporting any load that might be put upon it under ordinary circumstances, but nevertheless he believed he could show that bow and string girder was not of as economical a form for a bridge as a girder properly so called—*i. e.* a warren or a lattice girder. In the case of a bridge, under the most favourable circumstances the bow should have a curve corresponding to the curve of equilibrium due to the weight carried by the bridge (explained by diagrams). In a bridge with a bow and string girder of the simplest form, the top member must be equal in section throughout, or rather increased towards the ends, and would have the same section in the centre as a warren lattice or plate girder would have in the top and bottom member, but there was this important difference, that in the case of the warren lattice or plate girder, the top and bottom member would, unlike the bow and string, be diminished towards the ends, so that the top member of an ordinary girder would contain only two-thirds as much iron as the top member of a bow and string girder, and the tie, under similar circumstances, would be composed of only two-thirds the amount of iron as would be in a bow and string, and the diagonals of say a warren girder, would not do more than make up the top member equal to that of a bow and string. Under the very best circumstances, therefore, the bow and string girder must be heavier than an ordinary girder even without the diagonals, which must be provided for passing loads. It would appear, consequently, that a bow and string girder considered in the abstract could hardly be considered an economical, and therefore advisable form, unless there be some special reason for its adoption.

With respect to the joint pin of a warren girder, he had often found that the surface of the pin was inadequate to sustain the pressure brought upon it, or that would be brought upon it before the pin would be sheared or the bar pulled through. Suppose, for instance, a bar of a certain section which was wide and very thin, and a hole were made in this bar to take a pin of such a size that the sectional area would be only equal to the section of the bar, then it would be evident that the surface of the pin pressed upon by the bar, even allowing the half circumference to be effective, would be nothing like equal to the section of the pin. Thus, a bar 7 in. $\times 1 = 7$ sq. in. area, with a 3 in. pin, which would be 7 sq. in. section, would give only $4\frac{1}{2} \times 1 = 4\frac{1}{2}$ sq. in. surface pressed upon.

Mr. LATHAM said that the application of wrought iron to bridge building was of quite a modern date; but at the present time its

use was being carried to too great an extent. He thought that as every structure was subject to strains of compression and tension, and as cast iron was better suited to resist compressive strains than wrought iron, and wrought iron better suited to resist tensile strains than cast iron, that an economic structure should comprise a combination of both wrought and cast iron. With regard to the questions that had been raised as to the best mode of securing the cross girders to the main girders, he preferred rather to place them on the bottom flange of the girder than suspend them from it. He also considered that every part of a bridge should be accessible for examination and repair; and any bridge which did not offer facilities for examination was defective. The roadway of every bridge should be made impervious; otherwise, there was a leakage of water into the work, which, in addition to being a great nuisance to those who make use of the thoroughfares under such bridges, was prejudicial to the structure of the bridge itself, and the point bridge constructors should consider is the best mode of getting off with rapidity any water falling on the bridge.

The abutments of girder bridges at the present day are often neglected, and the result is that it is nothing uncommon to see them giving way, which may, in most cases, be attributed to the structure not being able to withstand the pressure of the ballast, which is brought into active operation owing to the presence of water at the back of the abutment. The injurious action of this water may be got rid of by the simple expedient of introducing drains constructed with a view to carry it away and prevent its hurtful accumulation.

Mr. H. P. Stephenson agreed with Mr. Reynolds as to the economy of lattice or plate girders over bow and string girders. In a bow and string girder the whole compressive strain is transmitted through the arch to the abutments, the string receiving the tension, the duty of the inclined lines being merely to transmit the weight to the arch; if the bracing were sufficiently strong to transmit the strain to the horizontal line, then the girder was no longer a bow and string girder, but became a trussed arched girder, and he believed the bridge in question should be considered one of that description, and not a bow and string girder.

Mr. Lefeuvre stated that, in his opinion, the bridge over the Thames was of an admirable design, although there were defects in some parts of it. The bridge was divided into 154 ft. spans, but owing to its having to carry four lines of rails instead of two lines, the bridge might be considered as divided into 308 ft. spans. He thought the diameter of the cylinders small, considering the immense weight they had to bear. He thought the cylinders should have been carried deeper into the clay. The diameter of

Digitized by Google

the cylinders in the bridge varied, and he should like to know whether any calculation was made when the different diameters were arrived at. He thought it a very ingenious construction, seeing that land cost so much on the north side of the bridge.

Mr. PENDRED said, that the largest bow and string bridge carrying a railway, with which he was acquainted, was that over the Shannon at Athlone. It had two spans; the upper member was a box, which took the whole of the strain. Mr. Carrington had said nearly all that he had to state with reference to drilling and punching of plates. After all it was a mere question of cost; he did not think there was anything like 10 per cent. in the difference between the results obtained. Punching machines were not what they should be, for after being used a little while the punches became blunt, when there was a drift action which seriously affected the strength of the iron. He thought punches should work at a high speed. From an article which appeared in the *Engineer* (Oct. 14th.), it would seem that the strength was in favour of the punched plates. It was much to be regretted that there were no well-authenticated experiments, in order to determine this question. In the best rivet joints there was at least one rivet in every hundred practically of no use, and in an inferior class of work there would be more than 10 per cent. of bad rivets. It did not appear that drilling could secure the correctness of the holes, so long as a drift was employed to bring the plates together subsequently.

Mr. PERRY F. NURSEY observed, that among the points advanced by the author of the paper, as being worthy of discussion, was that of the permanent way on the bridges of the Charing-Cross Railway. As the question had not been touched upon by any one present he would offer a few remarks thereon, and place before the meeting some particulars of the permanent way which had been adopted on the bridges of that line.

There could be no question that the permanent way of such bridges as they were dealing with, or in fact any railway bridges, was a matter which had to be carefully considered before it could be decided on. There were many elements at work which militated against the adoption of any ordinary arrangement. The character of the permanent way, doubtless, had a great influence on bridges, and involved much care in determining on the system to be adopted. The main points were, a sound and well-bedded sleeperage, good and even rails of a section, neither too heavy nor too light, a perfect arrangement of breaking joint in all parts, and an uniform adaptability of the way, as a whole, to the character of the structure carrying it, or, in other words, to have the relative elasticity or rigidity of each so balanced that, as a whole,

Digitized by Google

they—the permanent way and the bridge—should have a coincident action under traffic.

The system adopted on the Charing-Cross bridges appeared to embody these points. The rail used was of the flat bottom or contractor's section, weighing 75 lb. per yard run, 5 in. deep, and about $4\frac{3}{4}$ in. wide in the foot. The rails were placed on longitudinal timber sleepers, 14 in. wide × 7 in. deep, to which they were fixed by wrought-iron angle-chairs or brackets, 2 ft. 6 in. apart, centre to centre, placed in pairs. The brackets were 6 in. wide, and about $\frac{1}{2}$ in. thick in section, and the rails were secured in them by 1 in. screwed bolts, which passed through the well of the rail. The brackets were fixed to the longitudinal sleepers by $\frac{5}{8}$-in. spikes. The gauge was 4 ft. $8\frac{1}{2}$ in., and was preserved by transoms, 6 in. × 6 in., which were placed in the 4 ft. $8\frac{1}{2}$ in. way about every 6 ft., and in the 6 ft. way at intervals of from 12 to 20 ft. These transoms were connected to the longitudinals by means of 1-in. bolts passing through the latter, and of sufficient length to hold them well together. This made a very good permanent way, well suited to the purposes for which it was designed.

The only objection he would take to it was the use of the brackets in pairs. He thought the purpose would be answered equally well if they were placed *singly*, on the inside of the rail, the outer edge of the foot being held down by a dog bolt. And for the reason following, viz.: That, as the thrust of the traffic on the rail resolved itself into a force tending to overturn the rail—the outer edge acting as a fulcrum—so no good purpose was served by the outer bracket, the rail there needing only to be kept from sliding; but on the inside it was necessary to secure the rail by a bracket and fang bolt, or similar fastening, in order to resist the strain put upon it under traffic, which strain was tending to draw the bolt from the sleeper; the amount of leverage obtained being that due to the distance between the fang bolt and outer edge of the rail. Hence the outer bracket became a superfluity.

The ordinary permanent way of the Charing-Cross Railway consisted of a double-headed rail, fished, and weighing 75 lb. per yard, laid at a cant of 1 in 20. The fish-plates were 15 in. long, and 1 in. thick, bolted with four 1-in. bolts. Cast-iron chairs were used, weighing from 28 to 30 lb.; the width at seat of rail was 5 in., base of chair 13 in. × $5\frac{3}{4}$ in. Each chair was bolted to the sleeper with two $\frac{7}{8}$-in. bolts, with square heads and fang nuts. Oak wedges 8 in. long were used. The sleepers were 9 ft. × 10 in. × 5 in., placed about 2 ft. 2 in. centre to centre at joints, and about 2 ft. 10 in. at intermediate portions.

Mr. J. Lacey remarked that at the last meeting some allu-

sion was made to the pins which held the struts being defective, which had not since been explained, and he had heard it remarked also that the calculations were not so carefully made as they ought to have been. If it was so it might result in a serious weakness in the bridges.

Mr. A. Williams did not approve of the practice of suspending the cross girders to the bottom flanges of the main girders either with bolts or rivets. He considered that if they could not be fixed in their proper theoretical place on the top flange, they should rest on the bottom flanges of the main girders, and be bolted to the web of the main girders, they would thus tend to prevent any lateral twisting of the main girders, and, in his opinion, convey more directly the weight suddenly coming upon them to the main girders than if the cross girders were suspended to the bottom flanges, for in this case, any weight coming upon them must fall first on the rivet heads that connect them to the bearing girders; and from practice it is well known that nothing is easier than to render the head of a rivet useless by the workman either not hitting the rivet fairly on the top, as it should be, to swell the rivet out so as to completely fill the hole, or by using burnt rivets; in the first case, perhaps, only half of the head of the rivet is over the hole, and, in the second, not sufficient iron to make a proper head to the rivet. These are errors that can be avoided by proper supervision, but where a large number of men are employed it would be impossible to see every rivet knocked down. He did not consider that drilling was practically more advantageous than punching the holes of plates to be riveted together to ensure good work, for the first thing a workman did to bring the holes opposite to each other was to insert a pointed steel drift, and drive it in, to bring the holes of all the plates in a proper position, thus with drifting spoiling the drilled holes.

Mr. Parkes, in reply, said he did not know what calculations were made. In the Thames bridge there was a deficiency of sectional area, and in the bow string bridge there was an excess of sectional area. The load was 750 tons. If the distance between the centres of gravity of the upper and lower chord were taken at 12 ft. 9 in., it gave a central strain of 1.132 tons. For the bridge over the Thames, the strains in the upper and lower chord, at any vertical section, were equal for any load.

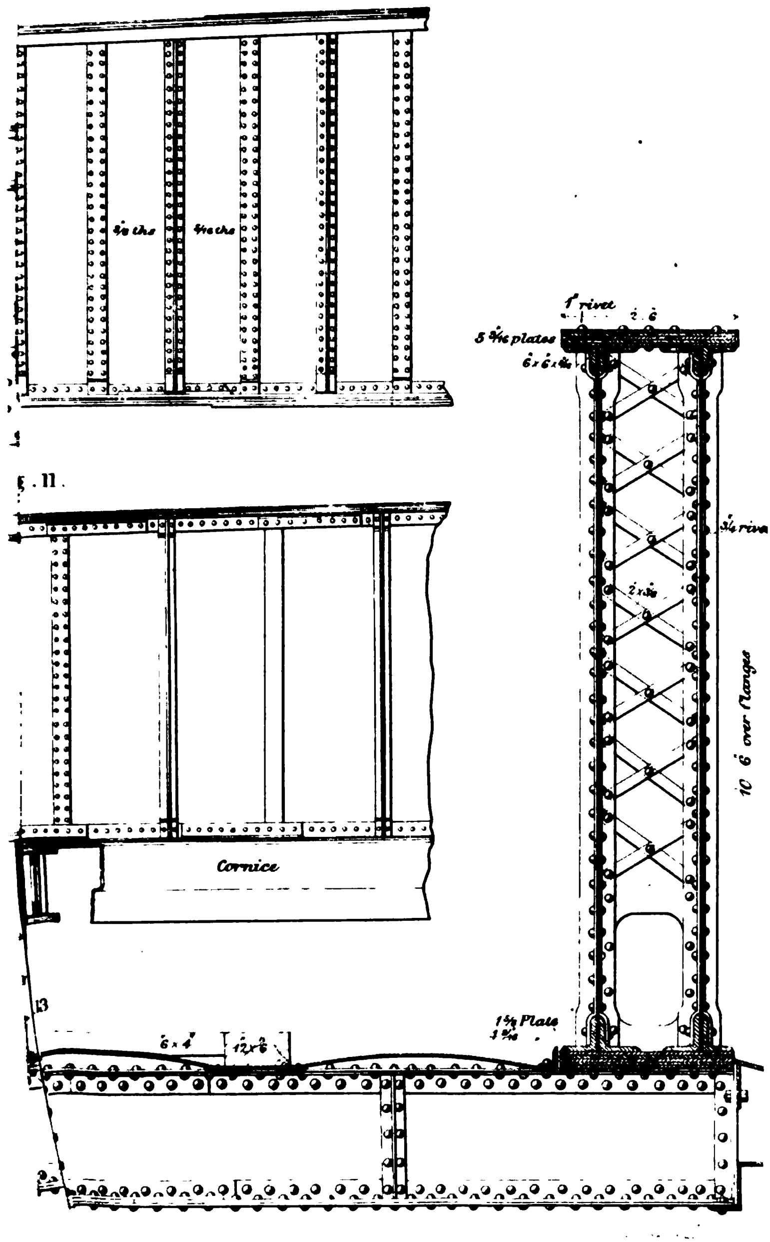
He was of opinion that iron was injured by being punched, and when a large number of similar plates was required drilling was the cheapest and best. The reason the distance between the centres of the cross girders was reduced in some cases to 3 ft. was to gain headway, by having the cross girders shallower, which would have required very heavy flanges if the 4 ft. dis-

Digitized by Google

the strains per square inch was less in the centre of the bottom flanges of the Charing-Cross Bridge girders than in the top flanges at the centre. He was of opinion that the strain on the bottom flange of those girders was less than in the top flange, and that the areas were properly proportioned. It was also mentioned as a defect in these girders that the pins for connecting the diagonal bracing to the flanges were not in the centre of the mass of metal in the flanges, but he was of opinion it was of very little consequence, as the effect of such position of the pins was to put a small transverse strain in the flanges caused by the tendency in the mass of metal of the flanges to get in the position of the line of strain, which was the centre line of the pin holes.

As regarded the question of punching or drilling holes in iron for bridge building, there was no doubt that drilling was the most satisfactory plan, as the engineer was practically certain as to the strength of the plates, &c., when the holes were drilled, but in the case of punching holes he was not at all certain of the result, as various qualities of iron would be more or less weakened, in addition to the metal actually punched out. Hard iron would be more injuriously affected by punching than soft iron.

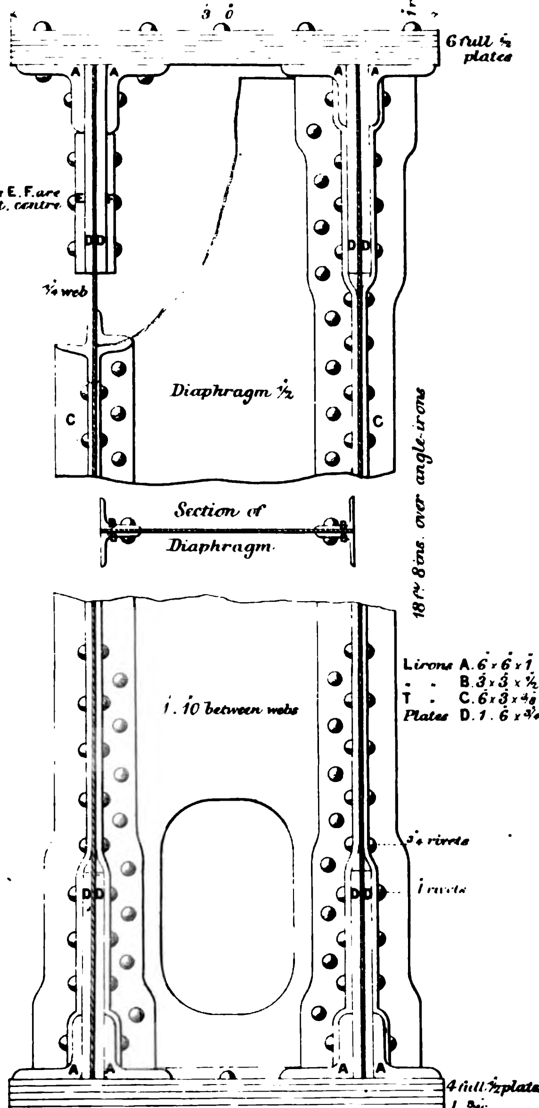
Digitized by Google



Digitized by Google

Digitized by Google

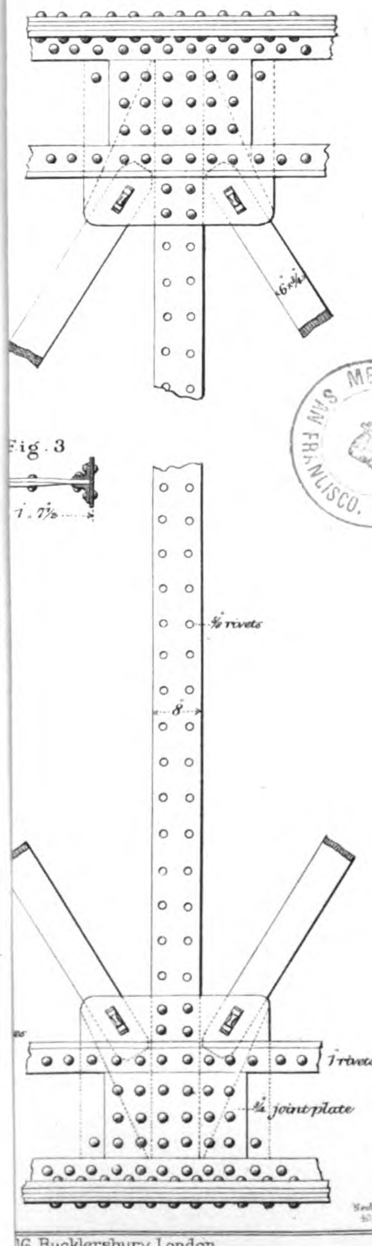
Fig. 7


3' 0"
1 rivets
6 full ½ plates
plates E. F. are apart. centre
¾ web
Diaphragm ½
Section of Diaphragm
18 ft 8 ins. over angle-irons
L irons A. 6 x 6 x 1
B. 3 x 3 x ½
T C. 6 x 3 x ⅝
Plates D. 1. 6 x ¾
1. 10 between webs
¾ rivets
1 rivets
4 full ½ plates

Digitized by Google

STT BRIDGE.

Fig. 2



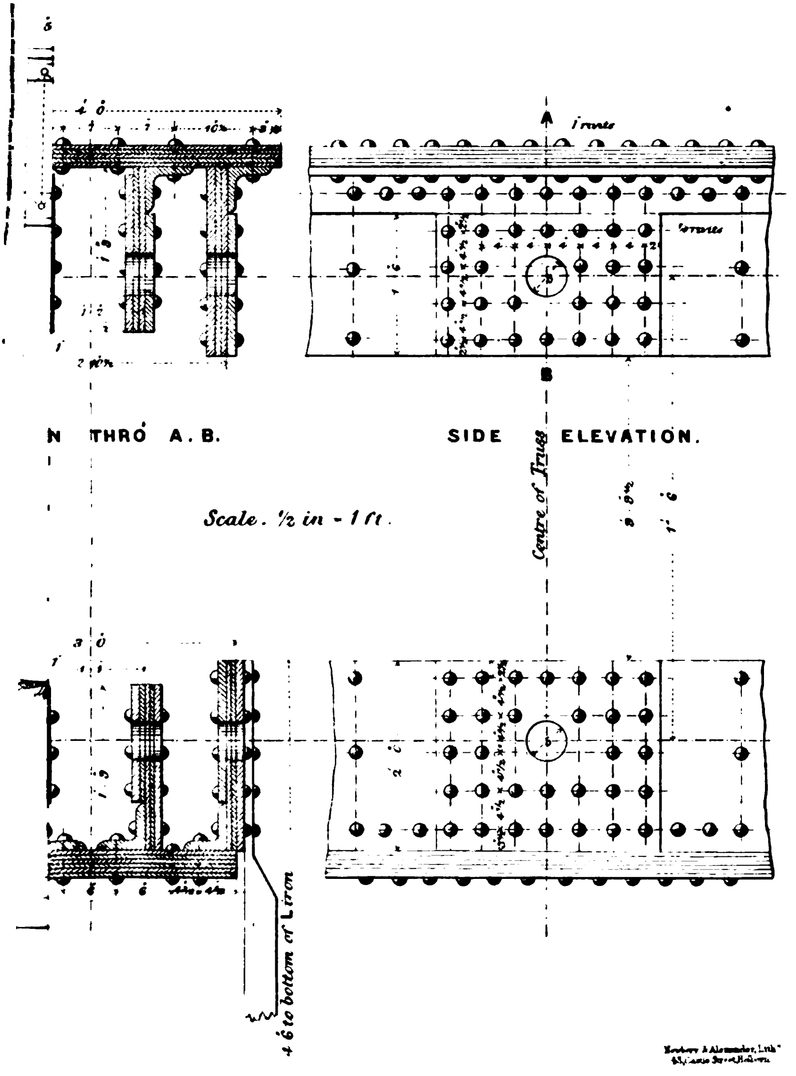
MECHANICS' INSTITUTE, SAN FRANCISCO.

Waterlow & Alexander, Lith.
40, Castle Street Holborn

16. Bucklersbury, London.

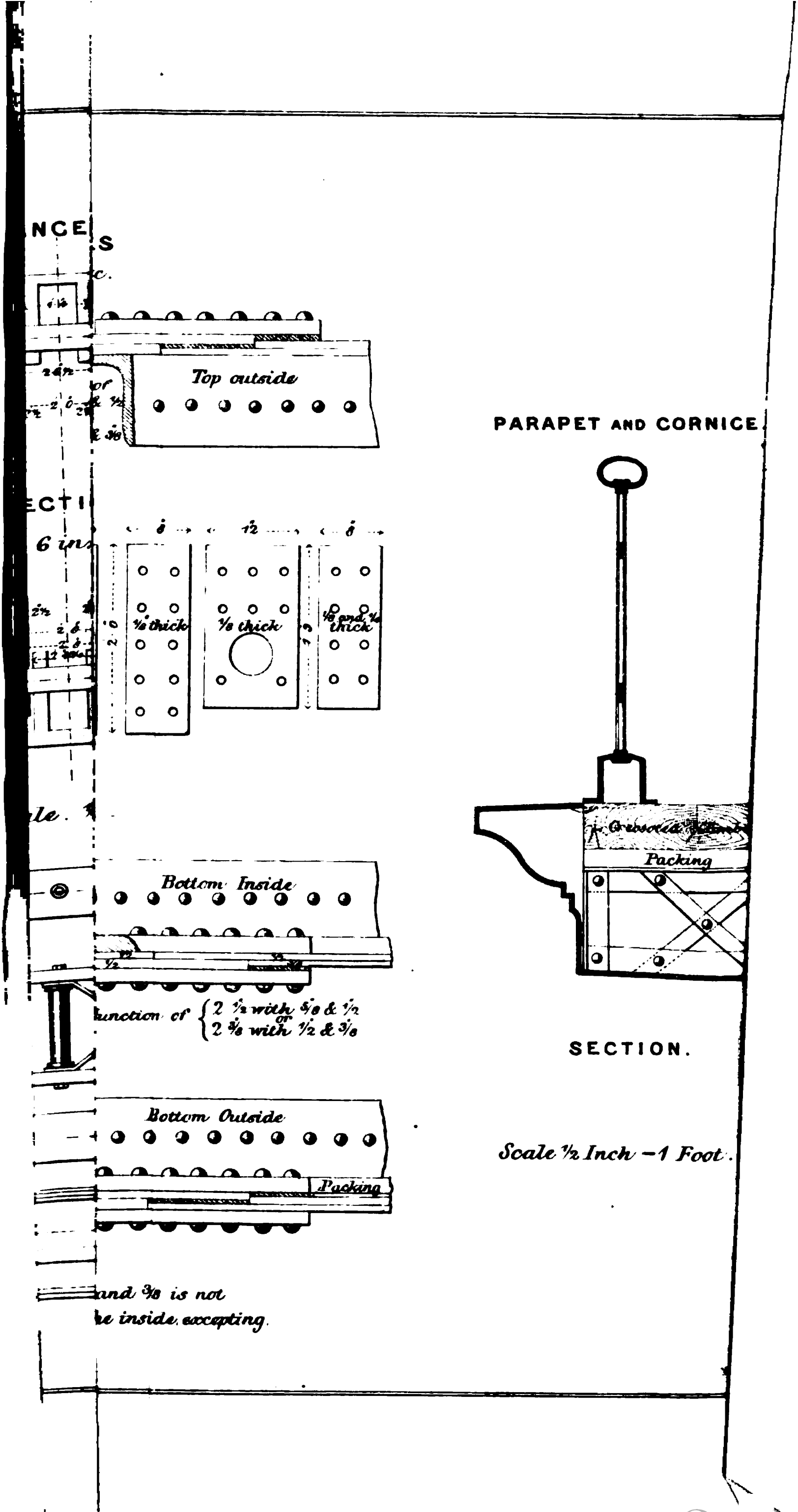
Digitized by Google

Digitized by Google



Digitized by Google

LIBRARY OF THE UNIVERSITY OF CALIFORNIA
Digitized by Google



Digitized by Google

Digitized by Google

November 7th, 1864.

H. P. STEPHENSON IN THE CHAIR.

ON THE ERITH EXPLOSION, AND THE REPAIR OF THE THAMES EMBANKMENT.

BY LEWIS MOORE.

ON the south side of the river Thames, between Woolwich and Erith, are several magazines used for the storage of gunpowder, belonging, some to Government, and some to private firms engaged in the manufacture of gunpowder. These are situated within a few yards of the bank of the river, for the convenience of loading and unloading by water, that being the most convenient and economical, as well as the safest method of transit. These magazines occur at intervals of half a mile or thereabouts. In the river, moored close to the north shore, were, until recently, three or four large hulks, used also for the Government storage of powder. Now, however, there exists but one, that being moored between North Woolwich and Barking Creek; the others, which formed part of the Government store at Purfleet, have been removed. On the north bank of the river there appears to be only one magazine in this neighbourhood beside the royal magazine at Purfleet. Full details of the arrangements of these magazines have so recently appeared in the public journals, that it is unnecessary here further to notice them, save as to their relative positions with regard to the subject of this paper; and this will be clearly seen on reference to the map of the general locality (No. 1.)

The scene of the recent explosion was on the south side of the river, in the Erith and Plumstead Marshes, and the magazines which were destroyed were the property of Messrs. John Hall and Sons, of the Faversham Mills, and of the Elterwater and Lowood Gunpowder Companies. The relative positions of these magazines to each other, and to the bank of the river and the adjoining cottages, &c., will be clearly seen on reference to

Digitized by Google

Diagram No. 2, which is from actual survey. The magazine of Messrs. Hall and Co. was a substantial brick building, 50 ft. square and two stories high, and was situated at the back of the river wall or embankment, on the marsh, at a level of 7 ft. or 8 ft. below Trinity high-water mark. From this magazine a jetty projected into the river to low-water level. This jetty was used for the shipment of gunpowder, and crossed the river wall on the level of the footpath. In this magazine, and in two barges, which at the time of the explosion were moored one at the end and one at the side of the jetty, there were about 42 tons of gunpowder. The magazine of the Elterwater Company was situated 64 yards to the eastward of Messrs. Hall's stores. This building was a similar construction, and measured 50 ft. by 28 ft., and contained about 4½ tons of powder. The next nearest magazines were those of Messrs. Curtis and Harvey, which are about 700 yards distant to the westward. The buildings adjacent were the manager's house and two or three cottages, inhabited by men employed at the magazines.

The river wall at this point consisted of an ordinary puddled clay embankment (the top of which was about 4 ft. 6 in. above Trinity high-water), battered about two to one, and faced on the river side with stones, to protect it from the wash of the sea; along the top was a footway about 4 ft. or 5 ft. wide. At the foot of the wall, on the land side, was the marsh that it reclaimed, and on the river side a shelving mud bank, falling at about the rate of one in six or seven to low water. The section will be clearly seen in Diagram No. 3.

Trinity high-water is 12 ft. 6 in. above ordnance datum, but the spring tides have been known to rise to a level of 16 ft.—14 ft. being the height to which they frequently rise. At the time of the explosion, which took place at twenty minutes before seven o'clock on the morning of Saturday, the 1st of October last, the tide was ebbing, and was within an hour and a half of low water—a most fortunate circumstance; for, had the accident occurred one hour later, it would have been impossible to reinstate the wall, and the marshes, as well as some of the surrounding country, must inevitably have been inundated, as it was impracticable (as afterwards proved) to have contended with the flowing tide in the limited time available. Of the immediate cause of the accident it will be here unnecessary to speak, as that will probably never be known; but, with regard to the results, there is more tangible matter to deal with. From the evidence afforded by the displacement of earth at various points, there is every reason to believe that there were three distinct explosions, occurring, probably, in the following order: 1st, the barge lying alongside the jetty and near the bank; 2nd, Messrs. Hall's maga-

Digitized by Google

zines; and, 3rd, the Lowood Company's magazines. The barge at the end of the jetty was presumed to have been empty, as no disturbance appears in the soil beneath where she lay, whereas in the other cases the earth was blown out to a considerable depth, presenting the appearance of a smouldering crater, with fissures in all directions. The reasons which lead to the supposition that the explosions occurred in the order above stated are that portions of the river wall were found in the hole or pit caused by the barge exploding, and this could only have been the case by the magazine exploding after the barge, and forcing the wall back towards the river, thrusting portions of it into the pit already formed by the barge. Had the magazine exploded first and thus ignited the barge, the ground beneath her would have been clear of fragments, as the wall would probably have been blown inland by the last explosion. The magazine last referred to would communicate with that of the Lowood Company, which, in its turn, was demolished. The concussion caused was felt from sixty to one hundred miles off; this was the result of the explosion of 46½ tons of gunpowder, or 1,040 barrels, each containing 100 lb. The effects to property, both immediate and remote, are universally known: as regards the river wall, a breach was made of 130 ft. in length, the earth being cleared away 8 ft. or 10 ft. below the level of the marsh, exposing the whole of the country to the rising tide for about five hours every high water, or twice in twenty-five hours. The extent of land positively imperilled would be about 4,000 acres, and should it have passed Woolwich and Greenwich by the large sewer, it might have done immense damage; the whole of the southern and eastern side of London being more or less below the level of high water. The full estimate of the impending calamity can be only realised by those acquainted with the levels of the localities referred to, and the character of the banks of the Thames. Diagram No. 4 shows a section of the river wall after the explosion; the dotted line shows a contour of the temporary dam. In an able article in the *Builder*, upon the subject of the catastrophe, the fortuitous conjunction of circumstances is thus described: "Every circumstance of time and tide, availability of competent direction, presence of men at the works of the main drainage, vicinity of a great and disciplined military force with tools and appliances, and even the soil at the spot, happened to be favourable; and a more serious disaster than has occurred within recollection, by a breach in an embankment of the Thames, was by the greatest exertions staved off and at length averted. The instance may be instructively compared with the experience of previous accidents, as related in various books, where the loss to landowners, and the injury to the navigation of the Thames, through the years' dura-

Digitized by Google

tion of breaches, and by the repeated failures of attempts to close them, is graphically related."

The author of the paper, residing in the locality, was enabled to be on the spot within half an hour of the explosion, and seeing that the sufferers were properly cared for, he proceeded to the immediate repair of the wall, although at the time the reinstatement of the wall before the return of the tide seemed hopeless, such was the magnitude of the gap. The first step was to set to work the men who were fortunately present, in number about forty; these were set to puddle the rents and deep fissures in the hole caused by the exploded barge, and which were below low water level, but were temporarily protected by the fragments upheaved around the edge of the hole; had not this been done before the water came into the hole it could never have been got at again, and the whole superstructure, however solid, must have been undermined and washed away. It may be readily inferred that the bases of operations were of the worst possible description, being lumps of earth and clay separated by large fissures several feet in length, and extending under the intended dam. The next thing was to send for assistance from the nearest point; fortunately this was obtainable at the Crossness works, about a mile off, and at the garrison at Woolwich, about four miles distant from the spot. At about ten minutes before nine o'clock the call was promptly responded to by the arrival from the Crossness works of about 350 navvies, with their picks, barrows, &c., who came none too soon to complete the puddling of this treacherous foundation before it was covered by the tide. Between ten and eleven o'clock, 1,500 military arrived fully equipped with some appropriate implements, and they devoted themselves entirely to the backing up with immense quantities of earth the works which the navvies were puddling in front, thus making it sufficiently substantial—consistent with speed and means at hand to contend with the now rapidly rising tide. In this, as is well know, by a manful struggle, they only just succeeded—racing as it were inch by inch with the rising waters.

Having given a general outline of the subject of the paper, it is now necessary to consider in detail the means employed and the measures taken to prevent the ingress of the water.

The first and greatest difficulty that presented itself was the portion blown out by the barge in front of the river bank, and below low water, inasmuch as the soil was very much broken up and disintegrated over a large area, and the time during which puddling could be done was exceedingly limited.

It may be here mentioned that an erroneous impression prevailed among some persons present, that it would be necessary to dig out this portion to a good bottom, in the usual manner of

Digitized by Google

commencing the construction of a river wall, and the author had much difficulty in persuading them that immediate puddling of the fissures and broken ground below low water mark was the only hope of succeeding, inasmuch as the cutting a grip would have occupied all the precious time to be employed in filling up. This puddling was most important in order to prevent percolation, the danger most necessary to be averted. When the navvies arrived from Crossness, they were immediately set to continue this important part of the work, and also the filling of the actual gap; it required some little time to arrange the number of men to advantage, but being accompanied by able superintendents, they were soon allotted to their separate works of digging clay—wheeling it to the spot—and carrying water for the punning, where the clay was well worked with iron punners.

While the puddling, &c., was being vigorously carried on by this large force of men, the military arrived, commanded by General Warde and Colonel Hawkins, R.E. The difficulty of immediately rendering available, without confusion, the labour of all these men in so small a compass and on the spur of the moment may readily be imagined. With the greatest promptness Colonel Hawkins adopted the suggestions offered him by the author, as to the method of proceeding. Several barrow roads were laid leading to the gap, numbers were employed in digging and loosening earth, filling and wheeling. The number of implements available for the use of the soldiers was, of course, limited; but, nothing daunted, they were formed into lines between the barrow roads, and passed from hand to hand towards the gap, the lumps of earth and clay dug up by those at the back, the whole of the clay and earth for that purpose having to be brought from a distance of 60 or 70 yards by the barrow roads and by hand, the soldiers passing lumps from one to another from this distance, which, when deposited in place, were immediately punned down perfectly solid. Having to deal with some 20 ft. head of water, it was necessary to extend the width of the dam at the base, which absorbed an incredible amount of earth, the width of the breach being 130 ft. When the tide had reached and filled the front hole, it was found that the level of the water was within 2 ft. or 3 ft. of the top of the progressing work. The tide rising very rapidly, fears were entertained that sufficient soil could not be obtained to enable the work to keep ahead of the tide. At this juncture, the military produced a quantity of bags used for making sand-bag batteries, and a number of men were set to fill them with the soil at the back of the work; these bags were at first being thrown in indiscriminately, when the author directed that they should be laid at the back of the puddled face in the form of an arch on plan, to receive the horizontal pressure

Digitized by Google

of the water. These bags were laid in courses, as shown in Diagram No. 5, and punned so as to come in perfect contact. By this means the bank could be raised of sufficient strength with about one-half the material, and the disposition of the men was so arranged as not to interfere with the other parts of the work. In this way about 3,000 bags were used, and it was satisfactory to find they answered the purpose admirably, but even with this assistance the tide was following the work very closely.

An alarm was now raised that the water was coming in, and it became apparent that there was considerable percolation under the dam—probably through the broken ground upon which so much labour had been bestowed in puddling—and making its appearance many yards at the back of the work, it was difficult to arrive at the treacherous point. This was most disheartening by the knowledge that a small stream would soon increase in newly-made earthwork and undermine the whole. The exertions were redoubled; but it is feared that these would have proved of no avail but for the timely settlement of the structure and consequent compression of the substrata. By this providential circumstance the leak was staunched, so that the settlement, apparently a source of great apprehension, proved really a matter for congratulation. Sole attention was now turned to raising the bank and protecting the face from the wash caused by passing steamers. Timber breakwaters were hastily constructed and floated in front of the work, and this in a great measure protected it from being undermined. By half-past one the tide was at its highest, and the bank was but a few inches above it; the structure successfully withstood the pressure of the water, but it was evident to all that the backing up must be continued before the danger was past, and the men, therefore, worked on until the tide had far receded. A large staff of men continued the operations throughout the night of Saturday.

On Sunday morning the bank was found to have settled some four feet, and, in consequence of high wind from the east and a heavy sea running, threatening to undermine the works, the author telegraphed to General Warde, Commandant at Woolwich, for 500 sappers and miners, who arrived in time to reinstate the dam. The whole of the past month has been occupied in restoring the wall to its original condition, and it is now as secure as any other portion of the embankment.

Breaches of the river walls reclaiming the marshes from the river Thames have been very frequent in times gone by. These have not arisen from causes similar to the one under consideration, but from high tides, defective sluices, and even rat-holes. In 1527, the river made an irruption at Plumstead and Erith, and so much land was submerged that it was not all regained

Digitized by Google

until 1590, a matter of sixty-three years. This breach occurred within half a mile of the present one, and there are now existing traces of the inland embankments by which it was reclaimed piecemeal. In the time of Henry the Eighth, the marshes of Plumstead and Lesnes, now the Woolwich practising ground, were submerged by the water coming in from the Erith breach. But the most recent, as well as the most important, was the Dagenham breach, which occurred in 1707, at a point exactly opposite the southern outfall works of the London sewerage. Continued attempts to stop this breach were made for eight years, but without success, when Captain Perry undertook to reclaim it. At this time the breach is stated to have been on one occasion 50 ft. below low water, or 70 ft. below high water, caused by the ingress and egress of the flood and ebb tides. Captain Perry, it is stated, employed 300 men for five years before he succeeded in stopping this breach, making thirteen years in all, during which time an immense quantity of the marshes were washed into the river, greatly obstructing the navigation of that important highway. The means he adopted were, firstly, forming sluices in the river wall to reduce the scour by allowing freer access to the water, and after so doing he drove dove-tailed or grooved piles from either side of the breach, protecting them, as he went on, with clay. The increased scour caused by this impediment threatened to deepen the channel so as to be beyond the reach of piles, and if the depth above stated was correct, it would have been impossible to have succeeded by this method, so the inference is that he chose a shallower portion of the breach; certain it is that he did succeed, although at a ruinous cost.

The Dagenham breach began with the failure of a sluice which had been allowed to get out of repair, and quickly extended from a gap of 14 ft., and ultimately led to the obliteration of a thousand acres of land. But that was not all: about 120 acres were actually washed away into the bed of the river by the flow of sullage, and the soil so washed formed a bank about a mile in length, reaching half way across the river.

Perry, in his work on Dagenham breach, proceeds to explain how this sullage driven into the river was deposited at the mouth of the breach, and above as well as below it, in the reaches of the Thames. He remarks that the deposit had been particularly detrimental to Erith Reach; and that even in Woolwich Reach, as he had been informed, the depth of water was lessened. All breaches, he observes, must be attended with a considerable flow of sullage into the river. After mentioning breaches that had occurred before his time, including one in the levels of Dagenham Beam, not three years and a half since, and several near Dagen-

Digitized by Google

ham since he had been concerned there, he says, he attributes all such breaches not to any damage from the tides washing down or running over the tops of the banks or walls, but to the bad workmanship, decay, or defect of the sluices or trunks which are made for the drain of the levels, &c.; and he alludes to sluices made of wood as a prevailing custom in England, and as generally insecure and unskilfully placed. He recommends, therefore, a law to oblige all sluices on the banks of the Thames to be made with stone, cemented with tarras. The reasons why they have not been made so, he thinks, are, first, that men in England are not very willing to depart from the way of their fathers; and, secondly, the matter of foundations. He argues, however, that if the foundations were constructed after the manner of buildings in Holland, the sluices might be formed of stone, or a sort of brick, as in Holland and Flanders, and might endure thousands of years.

The greater portion of the land bordering on the Thames, including the south of London, indeed, from Richmond to the Nore, is below the level of high water, and reclaimed by walls varying but little in their construction, the general character of which is an embankment, the face of which is puddled with clay to a slope of 2½ to 1, and protected from the wash of the sea by a stone face. In some cases where the steepness of the bank necessitates a greater slope, the face is stepped, and at each step a row of stakes driven to keep the stone facing in place. In constructing these walls, a grip about 6 ft. deep and 6 ft. wide is cut into the marsh to be reclaimed on the site of the wall, and puddled before the bank is made to prevent percolation. These walls and the necessary sluices for drainage require careful watching, for any portion failing would cause a catastrophe equal to the Dagenham or middle level inundation. The extent of these walls or embankments is very considerable.

It is a very remarkable circumstance that the marshes on the river side of the walls still unreclaimed and termed "salt marshes," are invariably at a level of high water, whereas the land reclaimed is generally 5 ft. or 6 ft. below that level. Whether the constant action of the tide raises the land subjected to it, or whether the absence of that influence allows the level of the marshes to subside, or whether it is due to both these circumstances, is a fit subject for discussion; but, be it as it may, there is no question of the fact that they do so exist.

Another material point for discussion is furnished by the supposition that failure had attended the attempt to stop the recent breach, and that the waters had regained possession of their old territory, some 7 ft. deep at high water over an area of from 3,000 to 4,000 acres. Assuming this to be the case, the breach would

Digitized by Google

be rapidly widened and deepened, and, were the old system adopted, the reclamation would occupy many years. It would be a work of from three to four times the magnitude of the Dagenham reclamation; and on the authority of Lambard, the land inundated by the breach which occurred in 1527, near the recent breach, as before noticed, was not all reclaimed in sixty-three years.

DISCUSSION.

Mr. Latham said that it did not appear to him that the arch form introduced into this bank had any special merits, as owing to the compressibility of the materials used it was impossible that the principle of an arch could exist beneficially; and in his opinion the backing of sacks acted merely as a counterfort and support of the puddle face of the bank, and as such he admired the plan as being one capable of being speedily executed in a time of great emergency.

The recent failure of embankments, and the ruin and devastation consequent thereon, must have had some effect in drawing public attention to those structures, and as we had, in this country, large and valuable tracts of land which had been recovered from the sea and were protected from inundation by banks; or as, under other circumstances, we had to construct embankments to stem back the mountain torrent for the purpose of supplying water for the use and benefit of our fellow-creatures, the construction of those embankments should occupy a share of the attention of the engineer of the present day; for not only did a vast amount of valuable property, but even the lives of our fellow-creatures, depend upon their stability. It was well known that when once a breach in an embankment was made it was most difficult to stop: and all who had experience in the construction of embankments, knew that after a few years a stratification took place, so that when an opening was made in a bank the new material would not join readily with the old bank, consequently such new material was very likely to be forced; to prevent that, it was the practice in the fens so to dispose the new material as to dovetail it into the older portions of the bank. The practice followed in the present day when constructing a bank of pervious materials and making it water-tight by a puddle wall in the centre of the structure was, in his opinion, wrong, and clearly against the principle of sound construction, as could be shown. The stability of a bank depended upon its weight, the breadth of its base, and the nature of the materials of which it was composed. A failure might arise from the bank sliding on its base, if of sufficiently rigid materials; from turning on the outer toe; or by the removal of the particles of the bank itself by effluent

Digitized by Google

water. It was quite clear that, if a bank was made of porous materials, the water would penetrate it as far as the puddle wall; the effect of that was to reduce the weight of the inner slope of the bank in the exact proportion of the volume of water the materials displaced; and to bring the pressure of the water to bear on the face of the puddle wall, so that the stability of a bank constructed of porous materials, with the puddle wall in the centre, depended upon the puddle wall and outer slope alone. From that it was also clear that, where we had porous materials to deal with, the puddle wall, instead of being in the centre of the bank, should form, or lie near to, the face of the inner slope. That being so, not only was the weight of entire material of the bank brought into action to counterbalance the pressure of the water, but that portion of the water that was supported by the slope, had a tendency to fix the bank on its seat; consequently, with banks constructed upon that principle, the longer the slope exposed to the water the greater would be the stability; as in proportion to the length of the slope, the weight of water, which had a tendency to fix the bank, increased; as also the stability of the bank itself, by reason of its centre of gravity being brought nearer the opposing forces, while the force that acted to force the bank forward or overturn it remained the same. As regarded the early breaches in the Thames embankments referred to by the author, they were interesting as historical facts; and as to gunpowder magazines he hoped the late explosion would be the means of causing some measures to be adopted for more securely stowing large quantities of so dangerous a commodity.

Mr. Bryant agreed with the plan of not quite filling the bags, but from Mr. Moore's description, it would appear that they commenced at the wrong place, immediately above where the puddling occurred. It was the simple effect of gravity that caused the safety, and not from any form that was given to the back of the bags. The arrangement for stopping up he considered very good. And as a means of prevention, or of repairing future breaches in a river bank, he thought it would be a good thing to keep a number of clay bags at several depôts along the banks of the river, for by them a breach could be repaired in a short time. It would be interesting to know how far the country was inundated when the breach took place in 1827, and had the last breach not been repaired, how far the country would have been inundated, and what difference there was in the high water mark there in former days compared with the high water mark at present, as up the Thames it had altered considerably.

Mr. Houghton said he quite agreed with Mr. Latham, that

Digitized by Google

the plan of adopting the form of an arch was wrong in principle, but he (Mr. Houghton) was not aware that such a form was adopted. They had more men than they could well employ, and they set to work to fill the bags indiscriminately, and the form they assumed happened to be that of an arch. It was undoubtedly an important question to effect improvements in the construction of powder magazines, and he thought they should be placed underground, and as far as possible, bomb proof, for this reason, that in case one magazine exploded, it would not extend to others, doing no other damage, but shaking them to their foundations. The banks in that neighbourhood were formed of 5 ft. of stiff clay, and about 7 ft. of blue clay, below that, 2 ft. of peat, and under that a large body of silt. As to when and by whom those banks were formed, was a point which required consideration. They were said to have been formed by the Romans, but that he did not believe, because, they were only too fond of recording all they did, and in respect of those banks, we had no data, nor information to fall back upon. The first breach in those banks it appeared occurred at Greenwich in 1295; many other breaches took place, but the largest took place at about the same spot in 1527, and lasted till 1590; as regarded the last breach, caused by the recent explosion, the work of reparation had to be done quickly, and they had to take what came to hand; they had plenty of assistance; but it was very questionable if the presence of the military on Sunday was at all necessary.

Mr. Pendred said that there was unquestionably great room for improvement in the construction of powder magazines, especially if they judged of the sample before them, shown in Mr. Moore's drawing. He did not think such a building was at all suitable for stowing powder. He believed the great protection lay in the perfect condition of the kegs in which the powder was stored. If those leaked, no precautions could arrest an explosion. He knew that at Woolwich the kegs were all made by machinery, and a maximum of safety thus realised, as such kegs did not leak. The lining the kegs with copper was considered too dear, but he did not know why zinc or some other sheet metal should not be used instead. It was known that powder could be exploded by percussion, as by striking it on an anvil with a heavy hammer. It was just possible percussion might lead, therefore, to an explosion, if the kegs were roughly handled.

Mr. Glynn asked if any reason could be assigned for the fact that the explosion at Day, Barker, and Co.'s magazine had not produced any effect on the river bank, although there was

Digitized by Google

certainly enough powder in the warehouse to have produced as serious an effect on the bank as that produced by the first explosion. To show the force of powder, and also to give some idea of the force expended in the explosion at Erith, he had arranged a table showing the amount of earth or rock thrown down, or moved, by 1 lb. of powder under various circumstances; those being taken from practice, and not from theory.

	lb.			lb.	
Round Down Cliff, Dover (chalk) .	85,232	thrown down	by	1	powder
Leith cutting, Tunbridge (hard white sand)	31,860	moved .	„	1	„
Plymouth (limestone) . .	22,400	„	„	1	„
Ditto, in small charges . .	8,900	„	„	1	„
Antrim, Ireland (white limestone) .	45,184	„	„	1	„
„ „ (winstone or basalt) .	32,430	„	„	1	„
East Dunmore (hard conglomerate) .	14,280	„	„	1	„
Londonderry and Colerne Railway .	22,400	thrown down	„	1	„ .

If we took the mean of those results, it gave us 32,832 lb. to 1 lb. of powder, and taking the amount of powder exploded at Erith to be 104,000 lb., we should find the force exerted to be 1,518,400 tons. And if we examined the principle of blasting rocks, we should see that the tamping hole bore a great proportion to the size of the charge of powder, and yet very little of the force of the powder was lost from that cause. That pointed clearly to the fact that, let the covering be ever so slight, the bursting force of the powder was scarcely diminished.

He would ask why, when the leakages were found in the river-wall, they had not thrown earth into the river in front of the wall, as it had been often found to help to stop up the holes in banks. He could not see how, supposing the wall had not been repaired in time, that the effects would have been so disastrous as anticipated.

Mr. Latham had quoted the failure of the reservoir bank at Sheffield, and stated that the front of the bank should always be made water-tight. Now this, he (Mr. Glynn) could not agree with, nor was it the practice of engineers so to do, for if the face of the bank was water-tight, what was the use of engineers putting a puddle bank in the centre of the embankments.

He could not agree with Mr. Bryant about the advantage of keeping bags filled with clay in case of explosions.

It was surprising to see the amount of carelessness among the men employed in those magazines, and he thought the owners should be exceedingly strict and see that the greatest care should be observed in them. He also thought if the powder, when stored, was divided into smaller quantities (say) 500 lb., it would

Digitized by Google

be desirable. If an explosion should take place at Upnor, where the powder was stored under the castle, the effects would be very disastrous, as it would be in fact a regular blast.

Mr. Bryant said that his idea was, that a quantity of bags should be kept empty at the engineers', or any convenient station. Clay bags were used at Westminster Bridge, so that when the tide came up the bags were filled and dropped in the opening, which served as a dam effectually.

Mr. Quick inquired if there were any modern instances of the walls of reservoirs being puddled both on the face and in the centre.

Mr. Kershaw stated that a reservoir at Disborough had a puddled wall in the centre, and also two or three feet of puddle on the face of the wall.

Mr. Glynn said there were several large reservoirs on the Peak Forest and Macclesfield Canals, and, as an example, there was one about one mile and a furlong in length, and the face of the bank of that reservoir was not water-tight, but had the puddle wall in the centre as usual. The face was lined with rubble stones to prevent the wash of the water wearing away the face of the bank, but not for the purpose of making the face water-tight.

Mr. G. W. Allan said it was unfortunate that the cause of the progress of explosions was not known, but it seemed it must arise from one of two causes, either from concussion, or the flame. But in either case the advantage of a sunk magazine would be great.

Mr. J. Lacey did not agree with the suggestion that the magazine should be under the earth. The reason it was covered so securely from the atmosphere was because the moisture of the atmosphere would spoil it; he thought magazines should be covered with a light material.

Mr. C. L. Light said the main question in the paper to be considered was to repair the breach, and not upon the construction of embankments. He thought great credit was due to those who had so effectively repaired the breach in so short a time. With respect to the bank not being disturbed opposite Barker's mill, when it exploded, it appeared to him, that the first explosion blew out a large basin of ground and so weakened the bank that the second explosion had more effect on the bank thus weakened. He agreed with Mr. Latham that the face of the wall should be puddled to prevent percolation.

Mr. P. F. Nursey said that there was a great quantity of powder in the large magazine, whereas, in the other there were but 4½ tons, and he thought that had there been an equal

Digitized by Google

quantity in each the results would have been similar in both cases, two breaches being made. He was inclined to think from the reasons adduced, that the lighter the magazines were made the better, the lighter materials having less damaging effect on surrounding property than heavy fragments.

Mr. OLRICK observed, that in storing powder great care should be taken that the kegs should be properly made.

Mr. HENDRY thought that the higher the magazines were built from the ground the better, as the explosion would not have such an effect on the surrounding objects, and that the roofs should be as light as possible.

Mr. PENDRED quite agreed that the roofs should be constructed of the lightest materials. Some two years since experiments were tried in France, two temporary buildings were erected for the purpose of experiment. One of them was fitted with a very light temporary roof, and the other with a heavier permanent roof. An equal quantity of powder was exploded in each. The light roof was merely lifted off, and the walls were uninjured, but the magazine with the heavy roof was entirely destroyed.

There were many unaccountable phenomena manifested by exploding gunpowder, from a number he might select one. An experiment conducted by General Probert, in which 4 lb. of gunpowder were spread loosely on a platform or table top, made of stout deal board, and resting on the loose soil of a garden bed freshly dug. The powder exploded on ignition, leaving the table wholly uninjured, but when the same quantity of powder was covered with a thick sheet of brown paper and fired, the table was shattered to atoms.

Mr. MOORE, in reply, stated that the bags were intended to have been filled, although they were not filled, in consequence of the rough state of the clay. The bags were brought round and arranged in layers. He contended that a bank in arch form, with the bags punned down perfectly solid, would be the most secure dam; that no more than half the quantity of material used in an ordinary bank would be sufficiently strong to resist the water, if the whole was arranged in the form of an arch, with the old river wall for buttresses on either side. Mr. Houghton's memory must indeed be bad if he did not remember that the bags were intended to be placed in the form of an arch. It was discussed by the military, and approved of by them; and the opinion of men accustomed to repair sea-walls was that one of the strongest forms of bank that could be made was a horseshoe bank. A question had been asked as to the quantity of land that was inundated by the early breaches. It appeared that the Plumstead and Erith Marshes were the same then as now;

Digitized by Google

but they might have somewhat subsided, and the tide might have altered. As regarded the latter, however, he thought it very likely it had not altered, because the levels were perfect up to the south side of the railway. As regarded the effect of the inundation, had not the breach been stopped, diagram No. 1 was supposed to represent its extent. The inundation must have extended from Erith to Erith Church, and to Woolwich practising ground. With respect to the puddled bags being water-tight, he thought they were not intended to be so. They were merely for the object of strengthening it by adding weight to it. Referring to the general construction of river walls on the Thames, he said he had been in communication with men engaged at Sheerness on similar works, who stated that the best way to proceed was to cut the trench in the centre down to the clay, and puddle up the whole of the face, and back it up with earth. The face was made perfectly water-tight, and percolation was prevented by the face being carried down a short distance below the surface. Mr. Glynn had offered some remarks on the power of gunpowder in connexion with blasting rock, &c., and said that sand and clay would offer very little resistance in stopping blast holes. He (Mr. Moore) agreed with Mr. Glynn as far as the clay was concerned, but not so as regarded the sand used for tamping; for he was of opinion that a granular substance like sand would offer as much resistance as if the hole were stopped up solid. He quite agreed with the remarks about confining gunpowder, for when it was confined it exercised an immense pressure, but when left in an open space it went off perfectly harmless. He did not agree with the remark that there was a superabundance of labour, for in a case of that kind, he thought it was impossible to have too much labour. Mr. Houghton had implied that the work would have been done as well without the military. On this point he (Mr. Moore) differed with him. He intended in no way to speak disparagingly of the navvies, as he had never seen work done so well or so rapidly. The exertions of the navvies were truly wonderful. But the military came in and did the whole of the backing up, and by the weight of the earth (if not the arch) prevented it being overthrown by the tide. He thought it perfectly necessary that the face of the river walls should be puddled, and he was satisfied that clay was used to puddle the embankments bordering on the Thames.

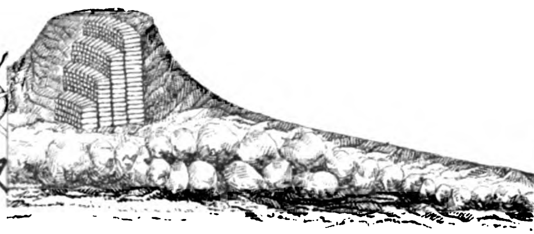
The CHAIRMAN said, there could be no doubt the repair of the breach was a perfect success; and in criticising the way in which it was done, it must be borne in mind that there was an extreme pressure of time. He agreed with Mr. Latham that those banks should be water-tight, although there was no doubt that in the

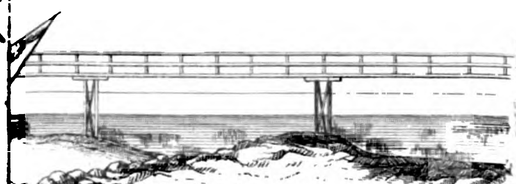
Digitized by Google

majority of cases that precaution was not taken. He also thought that it was most desirable those banks should not only have a water-tight face, but that the clay puddle bank should be carried down to the clay bed underneath. It would be very desirable, if practicable, to construct those powder magazines in isolated valleys, free from population, at any rate. They must all agree that to place powder magazines in the midst of a commercial population like that of Liverpool, London, or Portsmouth (close to the shipping), was highly improper. His opinion was that they should be placed in isolated positions, surrounded with walls and embankments thrown up around the whole. Attention should also be given to placing several lightning conductors round the magazine, instead of the lightning conductors placed upon the magazine.

Digitized by Google

N° 5.





Digitized by Google

LIBRARY
OF THE
UNIVERSITY
OF
CALIFORNIA

Digitized by Google

November 21*st*, 1864.

H. P. STEPHENSON IN THE CHAIR.

UPON THE SUPPLY OF WATER TO TOWNS.

BY BALDWIN LATHAM.

INTRODUCTION.

IF we look to man as the lonely inhabitant of the plain, or find him congregated with his fellow-men in our cities or towns; or to the beasts, birds, or reptiles that roam the wilds of nature unfettered and unrestrained; or to the majestic tree that rears its lofty head in the primeval forest; or the tiny floweret that we tread beneath our feet; or direct our attention still closer to a world of beings so minute, that, aided by the most powerful microscopes, many of them are only distinguishable by that quivering movement which indicates the presence of life, we find that they are all mutually dependent for life and existence upon water; not only are the animal and vegetable kingdoms so dependent on it for existence, but it also enters so largely into combination with the mineral matters composing the crust of the earth, that in its absence the fabric of this world would collapse and all nature become an arid waste. A subject of so much vital importance as water supply, especially to the human race, is deserving of careful consideration; as its influences, from a sanitary point of view, are attended with immense results for good or evil. The subject of water supply is one which has more or less occupied the attention of men of all ages, and in an historical point of view is well worthy of consideration, especially as with all the boasted advancement of the present age it is a question if our modern works for supplying water surpass those of ancient Judea, Greece, Rome, Mexico, and other places; indeed, all history goes to prove that wherever man had arrived at any considerable degree of civilisation, the subject

Digitized by Google

of water supply had a share of his solicitude. The volume of sacred writ contains records of many works of this character, and the works of Vitruvius not only urge upon us the necessity that exists for the supply of pure water, but point out the modes in which it may be procured and purified. So impressed were our progenitors with the importance of a good and abundant supply of water, that they were always careful to settle in those localities where it could be the most easily procured. In the course of events, it may have been that the original settlement increased in numbers, and extended itself to such a degree, as to have affected the quality or rendered the quantity of water insufficient for the demand, when, from necessity, more distant sources of supply have been laid under tribute to furnish what has been required. This has been the case with many of the towns of this and other countries. It was the case with ancient Rome and many of the cities of the East.

In these papers it is purposed to inquire into the various methods that have been, and that are still, adopted, to furnish supplies of water to large cities or towns, and as all supplies are furnished by the rainfall, this part of the subject will be first treated of, and following it, the various sources of supply will be dealt with in order as they are more immediately connected with it.

Rainfall.

All supplies of water being derived from the rainfall, this subject should receive careful attention, as the sufficiency and constancy of all works for the supply of water are dependent upon it. There are, however, circumstances connected with each mode of procuring a supply that in some measure may modify or alter the quantity, or affect the quality, of the rainfall of every district; yet there is no source, however remote it may appear from the rainfall, that is not directly or indirectly affected by the amount of that rainfall.

Rain is the result of the condensation of aqueous vapour, which is, at all temperatures, more or less suspended in the atmosphere. The quantity of aqueous vapour capable of being suspended in the atmosphere increases in a greater ratio than the temperature, and the phenomenon of rain occurs when the air, saturated with moisture, loses its temperature, and precipitates the excess it is no longer capable of containing in an aëriform state, either in the form of dew, rain, hail, or snow. It is found that the first causes of rain are identical with those that produce the winds and currents in the atmosphere—viz. the changes of temperature, to some extent the electrical state of the

Digitized by Google

SAN FRANCISCO

atmosphere, and the magnetic state of the earth; consequently it very naturally follows that the winds have a very close connexion with the rainfall. Thus, winds blowing from a warm climate over a great expanse of sea would be completely saturated with vapour, which, upon coming into a cooler climate, would be precipitated; on the other hand, a wind blowing from the frozen regions of the Arctic ocean, and deriving its moisture from the ice and snow of those severe regions, would, when it arrived in a warmer climate, by lowering the temperature of the atmosphere of that climate, diminish its power to retain aqueous vapours; and if, at the time, it was surcharged with moisture, a fall of rain must ensue. The physical conditions of every locality have some effect upon the rainfall. Thus, from observation, it has been ascertained that the rainfall is greater in mountainous districts than in level countries, which is probably owing to currents of air saturated with vapour striking against the mountain-sides, and losing temperature by contact or by reason of being compelled to ascend into higher and colder regions; there is, however, a limit to the effects produced by elevation, for there are regions too high to experience any heavy rainfall, for the rains of Switzerland and the Alpine regions are not greater than those in the north of this country. The amount of rainfall is considerably influenced by the position of the locality with respect to the currents in the atmosphere: for example, it is found that the prevailing winds in this country are westerly, and come to us from a warmer climate; after sweeping over the face of the great Atlantic ocean they are naturally saturated with moisture, and, striking the ridges and high lands on our westerly coast, discharge the greater portion of their burden there. Thus we find it is nothing uncommon in the counties of Cumberland, Westmoreland, and Lancashire, to have an annual depth of rainfall equal to 6 ft., while in Cambridgeshire, on the eastern side of the country, the annual rainfall seldom exceeds 22 in. The rainfall also varies with the seasons of the year, the rainfalls of this country being greater in winter than in summer, because the temperature of the atmosphere is decreasing in winter, and with it its capacity for retaining vapour, while in summer the opposite is the result. But it will also be found, as a rule, that heavier rains fall in summer than in winter, although there may be fewer showers; because in summer the atmosphere has greater powers for retaining moisture, so that when the causes that induce a fall of rain are brought into action, there is a larger amount of moisture to be precipitated. In Germany the rainfalls of winter and summer are about equal; at St. Petersburg the rainfall of winter is but little more than one-third the rainfall of summer;

Digitized by Google

while in Siberia the rainfall of winter is but one-fourth that of summer.

The rainfall of a district is ascertained by an instrument termed a rain gauge; and in fixing these gauges it should be borne in mind that the position and construction of the gauge has much to do with the value and accuracy of the results recorded; thus the fact has been well established that the amount of rain collected diminishes as the gauge is removed from the ground. Various reasons have been ascribed for this phenomenon. The most likely are that the cold rain drops condense more vapour in their descent, and carry it down with them; or, as has been supposed by Mr. Baxendale, of Manchester, that vapour that has lost its caloric of elasticity is capable of being suspended in the atmosphere in an invisible state, and is collected by the falling drops of rain. Rain gauges are of various forms, but those which have floats and graduated rods, that rise with the rainfall, are objectionable if the rod is exposed, as they are likely to exaggerate the rainfall of any district, because the rod collects rain driving in an angular direction.

The amount of rainfall recorded by the gauge cannot all be made available by the engineer in his works, as there are causes in active operation which render it impossible to collect the entire rainfall of any district. Therefore the engineer has to deal with resultants that arise during the constant and incessant circulation of water, and before he can arrive at correct results he must carefully consider the subjects that affect the rainfall.

Digitized by Google

RAINFALL TABLES.

Name of place.	Altitude above sea level.	No. of years' observation.	Minimum rainfall.	Maximum rainfall.	Average rainfall.
	Feet.		Inches.	Inches.	Inches.
Aberdeen	115	6	27.07	43.78	32.55
Allenheads, Westmoreland	1300	7	38.3	58.5	47.9
Applegarth, Dumfries	...	12	24.0	44.1	33.8
Arbroath	75	5	23.69	30.5	27.23
Ashton, Leicestershire	...	...	...	...	40.0
Aylesbury, Bucks	...	3	22.5	34.7	28.4
Bacup	...	...	...	...	40.0
Balfour	130	4	24.38	27.82	25.94
Barry	35	5	23.78	38.16	28.73
Bath, Somerset	...	3	...	37.8	32.4
Bedford	100	9	17.9	32.3	22.3
Belfast	...	...	32.0	40.0	36.0
Birmingham	380	6	19.9	29.2	25.5
Bolton, Lancashire	320	10	42.2	58.6	49.5
Boston, Lincolnshire	30	25	16.1	28.8	23.1
Bowhill	653	4	25.35	35.23	26.34
Breock, St., Cornwall	...	13	32.0	51.9	41.0
Braemar	1110	6	27.97	40.06	33.90
Bressay	25	4	31.44	50.8	37.68
Bury, Lancashire	300	13	28.6	50.6	41.7
Caermarthen	...	...	...	...	42.0
Caleton Mor	65	5	37.3	49.37	44.46
Carlisle	...	24	25.68	35.84	30.57
Chapel-en-le-Frith, Derby	1121	8	33.0	52.3	43.0
Chatsworth	...	16	...	...	27.66
Chiswick, Sussex	25	25	15.2	29.7	24.0
Chorley, Lancashire	...	...	...	...	48.0
Clifton, Somersetshire	228	10	22.6	39.5	31.02
Cobham Lodge, Surrey	80	25	16.8	31.7	24.5
Cockermouth	...	3	34.9	55.4	45.4
Croydon, Surrey	...	11	16.26	33.8	25.33
Denton West, Westmoreland	276	5	29.85	40.36	36.4
Dewsbury	...	...	...	...	45.0
Dickleborough, Norfolk	120	10	18.4	32.4	25.0
Douglas, Isle of Man	103	7	24.5	37.9	30.3
Drumlanrig	186	5	39.95	50.33	46.79
Dublin	...	...	...	...	45.0
Dukinfield	...	...	...	...	36.0
Dumfries	...	16	...	...	52.0
Dundee	100	7	...	...	33.0
Dunfermline, N.W.	230	7	22.45	42.80	35.28

Digitized by Google

RAINFALL TABLES—*continued.*

Name of place.	Altitude above sea level.	No. of years' observation.	Minimum rainfall.	Maximum rainfall.	Average rainfall.
	Feet.		Inches.	Inches.	Inches.
Easdale	25	3	48.4	60.4	54.83
Edinburgh	300	21	15.27	32.59	25.6
Elgin	28	5	23.92	29.36	26.6
Ely	140	6	20.0	34.30	25.13
Epping, Essex	...	10	22.5	32.2	26.6
Exeter, Devon	141	25	24.0	39.2	29.2
Fairfield, Lancashire	320	8	24.8	40.7	31.5
Fassaroc, Wicklow	200	8	24.7	57.5	36.8
Falmouth	120	9	31.7	50.1	40.1
Felthorp, Norfolk	...	5	20.0	25.8	22.6
Fethicairn	241	5	23.31	41.43	28.95
Gatesgarth, Westmoreland	326	3	...	...	117.2
Gilmonton, Lanark	600	5	35.3	60.3	47.7
Glasgow	200	6	33.5	46.2	37.43
„ Waterworks	...	...	...	...	60.0
Glencore, Rutland Hills	734	19	23.5	45.9	36.11
Goodamoor, Devon	600	16	41.6	70.1	56.8
Gosport, Hants	30	7	24.0	34.3	30.2
Grasmere, Westmoreland	180	3	...	...	107.5
Great Gable, do.	2925	2	...	...	89.4
Greenock	64	5	50.5	68.5	60.0
Greenwich Observatory	143	12	16.4	33.2	23.93
Guernsey	123	9	25.6	49.1	36.3
Hastings	...	12	22.36	43.53	31.98
Hawarden	260	9	20.3	40.4	27.2
Honiton, Devon	...	5	25.5	41.7	33.2
Huddersfield	...	...	...	...	33.0
Hungerford, Berkshire	320	12	19.28	34.07	26.58
Hyde, Lancashire	320	10	30.6	39.6	35.2
Kendal	...	25	...	...	53.944
Kettins	228	5	31.09	38.17	33.71
Keswick, Westmoreland	258	3	47.0	74.3	60.1
Kilmarnock	...	...	...	...	33.0
Kingston-upon-Hull	...	...	28.0	30.0	...
Lampeter	420	5	36.7	55.5	43.2
Lancaster	...	20	...	...	39.71
Leek	...	...	...	...	45.0
Leicester	...	...	...	...	24.0
Lincoln	...	...	...	...	24.0
Linton, East	90	5	23.32	34.95	27.65
Liverpool	37	23	22.2	49.5	34.7
London	...	40	...	...	25.3
Macclesfield	...	...	...	...	40.0
Manchester	...	33	25.0	45.1	36.14
Millfield, near Stirling	169	4	32.1	44.74	36.81
Milne Garden	100	...	25.8	32.8	29.94
Moss Loch, near Rochdale	500	11	25.9	37.7	30.3

Digitized by Google

RAINFALL TABLES—*continued.*

Name of place.	Altitude above sea level.	No. of years' observation.	Minimum rainfall.	Maximum rainfall.	Average rainfall.
	Feet.		Inches.	Inches.	Inches.
Newcastle-on-Tyne	121	2	...	...	89.4
Norwich	39	11	20.3	33.2	26.5
Nottingham	203	15	17.4	38.5	26.65
Oldham	...	...	...	...	35.0
Ormskirk	...	...	29.0	40.0	...
Oxford	210	11	17.7	40.4	27.2
Paisley	...	...	...	...	51.33
Pencarrow, Cornwall	...	3	37.9	57.3	45.3
Penzance	40	9	34.7	53.9	43.1
Perth	66	5	30.50	38.36	33.53
Plymouth	30	10	27.9	45.4	35.7
Preston	...	...	...	...	43.0
Reading, Berks	...	17	21.2	32.8	25.4
Rochdale	500	16	34.4	61.1	46.7
Rugby	...	...	...	...	22.0
Rusholme, Lancashire	...	...	30.0	40.0	35.0
Sandwich	100	5	27.41	44.51	36.33
Scomie	26	4	39.4	42.87	41.11
Seathwaite, Westmoreland	...	3	...	...	140.6
Shipley	...	...	...	...	30.0
Southampton	60	...	28.9	48.7	...
Sowerby Bridge, York	300	11	26.5	30.8	27.2
Sparkling Tarn, Westmoreland	1900	2	...	...	124.0
Stobo Castle	600	4	16.86	25.6	21.78
Stonyhurst	381	9	37.6	59.3	45.2
Storroway	70	5	35.69	45.84	41.62
Styehead, Westmoreland	1290	2	...	...	92.8
Swaffham Bulbeck, Camb.	...	7	19.6	29.7	23.8
Swansea	...	...	...	...	36.0
Stractine	200	6	29.72	38.16	32.88
Stubbins, York	...	11	26.1	40.2	32.3
Thirlstane	558	5	23.68	28.86	27.35
Thurston	320	5	23.90	37.16	29.21
Tongue	40	4	30.3	46.7	40.96
Torquay	120	7	19.4	50.2	29.2
Tottenham	50	7	19.3	29.1	24.8
Tyndum	792	3	...	...	74.2
Wellington	160	20	17.8	33.3	24.9
Whitehaven	90	3	35.0	52.0	47.0
Wigan	...	...	...	...	40.0
Wrexham	...	...	...	...	38.0
Yester	420	5	29.73	42.35	34.5
York	50	9	18.5	29.4	23.4

Digitized by Google

Circulation of Water.

The first source of rainfall is the ocean; by evaporation a portion of its waters are raised into the atmosphere to be again precipitated in the form of rain; of this a portion is again evaporated—another portion absorbed, while another portion may find its way back to the ocean—its original source. Thus it is that "the circulation of water is incessant—now in the ocean, now in the atmosphere, now in the tissue of plants or animals, now in the crust of the earth, now coursing its surface; and anon in the ocean again, to repeat the same circuit, and this without interruption while the present relations of the universe endure. In general this circulation is slow and gradual—so slow, that the spherule of vapour now rising from the ocean may be years, or even ages, in returning to its native source. Disseminated in the tissues of plants, or locked up in the crystallisation of minerals, its cycle seems interminably arrested, and yet we know that decay and degradation will some day or other bring about its liberation. On certain occasions, however, and in certain localities, its circulation is so rapid that you absolutely perceive the hazy vapour ascending from the sea, rolling landward in mist and cloud; coming in contact with cold mountain-peaks, condensing into rain, and falling in torrents to augment the runnels and runlets. From runnel to stream, from stream to river, the mass swells, and hurries downward and onward to the great receptacle whence the light and filmy vapour originally arose, there to resume the same career, and perform analogous functions." The water evaporated from the ocean may, for all practical purposes, be said to be perfectly pure; but in the course of its circulation it is constantly contracting impurities, and as frequently undergoing processes of purification. In this mighty circulation it performs important functions in re-arranging not only the tissues of plants and of animals, but in absolutely re-arranging the strata of the earth. All matter is animated in its presence, and it is, as it were, the life-blood of all creation. It is during the progress of this incessant circulation, as has been before observed, that the engineer has to deal with it, and in doing so he will find the available rainfall dependent upon certain conditions, such as the nature of the soil, the declivity of the district, and the rate of evaporation. If the nature of the surface receiving the rainfall is naturally, or has been made artificially impervious, there will not be any absorption, and evaporation will be the chief cause for any diminution of the quantity.

Digitized by Google

Evaporation.

It is extremely difficult to arrive at correct results as to the amount of evaporation taking place at any time either from land or water, as there are so many circumstances and conditions that may affect the subject and lead to errors: considerable caution must, therefore, be exercised in dealing with the results, and it is always better to be on the safe side, that the calculations of the engineer may not lead to a diminished supply of water. It is quite clear that the rate of evaporation from land is very much less than the rainfall, otherwise we should have no rivers or springs. But the rate of evaporation from water surfaces considerably exceeds that from land, and in some cases the rainfall. Dr. Dalton found, by experiment, that the mean daily quantity evaporated from a vessel of water freely exposed to wind and sun, was, in March, .033 in.; in April, .055 in.; in May, .075 in.; in June, .063 in.; in July, .122 in.; and in the hottest weather of summer he never found the rate of evaporation to exceed .200 in. per day. Experiments made by Mr. Luke Howard, at Plaistow, on the rate of evaporation from water surfaces gave .912 of the rainfall as the amount evaporated. In similar experiments made by M. Valles, at Dijon, the rate of evaporation was ·966 of the rainfall. A like experiment, made at the same time, but from a smaller vessel, gave a greater amount of evaporation, which in this instance exceeded the rainfall of the period. It is probable that the mean rate of evaporation in this country from water surfaces may equal 36 in. or 37 in. In other countries the rate will increase considerably with the mean temperature.

The rate of evaporation from land surfaces must be, as has been before observed, much less than the rainfall; but the precise rate it is difficult to arrive at, as the character of the soil, the state of its cultivation, and its general contour, affect the results very much. Thus, if the land is uncultivated and exposed, it would, by the action of the sun and wind, be dried very quickly; and when once the surface is dried, the rate of evaporation falls off; but in the cases where verdure covers the surface, whether it be in the nature of woods, or of grassy meadows, the vegetation protects the surface of the earth from the direct action of the sun and wind; yet in a more regular way evaporation is progressing, as the roots of trees and plants are abstracting the moisture from the soil, and retaining but a small portion, they give off the remainder into the atmosphere in the form of vapour. Experiments made by Bishop Watson on evaporation, on a bright and hot sunny day when there had been no rain for a month, give the rate of evaporation from grass as .035 in. in twelve hours. A similar experiment made

Digitized by Google

after a thunderstorm gave .087 in. From an experiment made by Mr. Lawes a plant of wheat was found to exhale 100,000 grains of water in 172 days, or the period of growth: which would be at the rate of 2200 gallons of water evaporated from an acre of ground per diem, representing a rainfall of .36.5. It is probable, however, this is rather a high estimate.

The effect of evaporation, either from land or vegetation, is also a check upon itself, for as the circumstances arise to create a fierce rate of evaporation, they are in some measure counterbalanced by the cooling effect evaporation has upon the surface from which it takes place. The circumstances that favour evaporation are heat, a dry atmosphere and a low barometrical pressure or decreased weight of the atmosphere upon the evaporating surface; winds or currents of air also greatly promote evaporation, for they not only bring the air into closer contact with the water, but remove the particles of moisture as they are converted into vapour, and are continually bringing a fresh volume of air into action to receive its load of vapour. The rate of evaporation from most surfaces is in some measure compensated for by the deposition of dew, which is very rarely estimated with the rainfall.

Absorption.

The amount of rain capable of being absorbed by the surface upon which it falls depends, in a great measure, upon the temperature, the geological formation, and physical outline of the district. In making calculations as to the amount absorbed, we must bear in mind that the area of the surface is the only constant quantity we have to deal with, as its condition and capability for absorbing water vary considerably with the seasons of the year. Under such varying conditions the amount of water absorbed, and capable afterwards of being used, when issuing from springs, or by sinking wells, is extremely capricious. The greater the quantity of water evaporated or retained by vegetation, the less will remain to be absorbed. Rain descending upon a dry and parched surface in the heat of summer, or during the occurrence of drying winds, will be nearly all evaporated, so that the rate and amount of absorption depend materially upon the absorbent properties of the soil. Thus in the sands of the red sandstone formation the rainfall is absorbed as fast as it touches the surface, and the same may be said of the rain falling in many places on the chalk formation, while upon the clay soils, or impervious formation, the greatest part of the rain would generally be directly conveyed away by surface streams. The contour of a country, in a measure, affects the rate of absorption, as the rainfall on mountains or hilly districts

Digitized by Google

has a greater tendency to gravitate rapidly to the rivers, while on table-lands the water lingers, and consequently such lands are favourable to absorption.

Experiments made by Dr. Dalton, extending over three years, on the new red sandstone formation, show that 25 per cent. of the whole rainfall percolated to a depth of 3 ft. Experiments made at Fernbridge, in Yorkshire, by Mr. Charnock, on the magnesian limestone formation, resulted in giving but 19.6 per cent. of rain percolating to a depth of 3 ft., and a like experiment made by Messrs. Dickenson and Evans, on the sandy gravelly loam which covers the chalk about Watford, gave as much as 30 per cent. of the rainfall percolating to a depth of 3 ft. In the latter experiment the average rainfall was found to be 26.33 in. per annum, and the average mean filtration 7.92 per annum. Of this quantity 7.34 in. were absorbed between October and March inclusive, which was at the rate of 55½ per cent. on the rainfall of that period, whilst between April and September inclusive only .58 in. of rainfall was absorbed, which was at the rate of 4½ per cent. of the rainfall of that period. From this experiment it appears that the largest amount of rainfall is absorbed during the months of November, December, and January, when, practically, all may be said to be absorbed; and that the least amount at any time absorbed was in the month of August, when, practically, it was nothing. It has been calculated by Mr. Beardmore, C.E., that of the rainfall absorbed in winter 60.7 per cent. is carried off directly at the time of the rainfall, leaving 39.3 per cent. to supply rivers and wells; and of this probably only 3¾ per cent. of the rainfall absorbed really goes to furnish a supply for wells, which in a measure will account for the failing of many ordinary wells in certain seasons of the year. This process of absorption plays a very important part in the economy of nature, as by it the rainfall is stored for the purposes of utilisation by both the vegetable and animal kingdoms. Were it not for this our rivers would only flow in times of rainfall, and at such times their impetuosity and floods would be so great as to prove a great drawback to their subservance for the purposes of man, and at other times their channels would be dry, which would probably be a greater disadvantage, as all vegetation would suffer materially, if it could survive the droughts we should experience; as it is, the water falling on the surface penetrates it to various depths, forming for itself subterraneous reservoirs, and it is from these reservoirs the water is emitted which keeps our rivers flowing and supplies water for vegetation, even in the time of the greatest drought.

Digitized by Google

Modes of obtaining Supplies of Water.

Having considered the two great causes that tend to diminish the amount of the rainfall that can be made available by the engineer in his works, it is now necessary to direct attention to the various expedients adopted for securing and furnishing supplies of water, and which may be classed under the following heads:—

1. By the interception of the rainfall before it reaches the ground, or before it has penetrated it; such, for example, as supplies taken from rain collected on the roofs of houses, or on the paved and impervious surface of our yards, courts, &c.
2. By the interception of the rainfall after it has reached the ground, but before it has run off by its natural course.
3. From rivers and streams.
4. From natural springs.
5. From wells.

Rainfall collected from Roofs, &c.

One of the simplest modes of securing a supply of water is by collecting and storing the rainfall that falls direct upon the roofs of our houses, or upon the paved surfaces of yards, &c. This mode is no doubt very ancient, and was probably one of the first expedients adopted for securing a supply wherever man had advanced to that state of civilisation as to require a house with an impervious covering for his shelter. The amount of surface available and suitable for receiving the rainfall is generally limited, so that the quantity of water capable of being stored is also limited; yet there are many places that depend upon this mode for procuring their principal supplies of water. A large portion of the supply of water for Jerusalem, Constantinople, and other ancient places, was procured by storing the rain water in underground cisterns, some of which are in use to the present day. The city of Venice is an example of one of many places supplied principally by rain water; but it is found that, in long, dry seasons, the inhabitants of such places as are dependent on this mode of procuring a supply of water are often put to great straits for a supply; and if we assume that 60 ft. of roof or other impervious surface is available for each individual of the population, with an annual rainfall of 30 in., if all of it were collected and stored, it would only give two and a half gallons per day as the quantity for each individual. Professor Leslie made a calculation, with respect to a lofty house in Paris, containing twenty-five persons, and he found that each person might procure a supply of a little over one gallon per day. When these quantities are compared with the twenty to fifty gallons per head per day at present used by populations having a constant supply

Digitized by Google

of water, it is easy to see the disadvantages of depending entirely upon the rainfall collected on roofs and other surfaces connected with our dwellings as the sole mode of supply; at the same time it is advisable in many, if not in every house, to utilise the rainfall that can be procured on the site, as all such water, if collected and used, will have a good effect in diminishing the supplies it may be necessary to furnish by other and artificial means; moreover, such supplies of rain water are, in many districts, invaluable, where the water is naturally hard, and soft water for the toilet and some other purposes is an absolute requirement.

The quantity of rain water collected from the roofs of houses in cities or towns is invariably more or less varied in the degree of its purity; indeed, it has been determined that pure water can nowhere be met with in nature, and the purer the water the more likely it is to contract impurities. The impurities contained in rain water are contracted partly by absorbing gases from the atmosphere in its descent, and partly from the impurities it meets with upon the surface that receives it, such as dust, insects, and soot, which accumulate during dry weather; and these impurities, although affecting the quality of the water for some purposes very slightly, yet when they are allowed to accumulate in the cistern or storing reservoirs, undergo constant decomposition, and injure the quality of the water for many purposes. But inasmuch as many of these impurities, when first contracted, are of a mechanical character, they can be easily removed by a process of filtration, and as such system of purifying the rain water before it enters the cistern or tank is easily effected, it is very desirable that it should in all cases be done. In Venice this system has been adopted with great advantage and success, and Fig. 1, Plate 1, is a representation of the mode by which the water there is freed from its mechanical impurities; consisting of two wells concentrically placed. The inner well forms the pure water store, the outer receives the rainfall. In passing from the outer to the inner well the water has to filter through a stratum of sand. The best way to preserve the purity of rain water collected from the roofs of our dwellings is by preventing its exposure to light and heat; this can best be done in underground tanks, which should be well ventilated. It often happens that for the sake of convenience, tanks or cisterns are constructed and placed in the upper portion of our dwellings, so as to furnish a supply without having to use mechanical means to raise it; but the purity and freshness of the water can never be compared with that stored in underground receptacles. The size of a tank for storing the rainfall should be sufficient to give a supply during the longest periods of drought, and consequently will depend upon the amount of the rainfall, the area of the roof or other

Digitized by Google

surface, and the quantity of water required. Provision should be made to store not less at least than 90 days' supply, otherwise the supply may fail during long periods of drought and when it is most needed. Mr. Bateman, C.E., has observed that droughts "vary in extreme length from, probably, 120 days on the west coast of the backbone of England to 240 on the east side."

Water Supplies taken from Collecting Areas.

The rain falling upon the surface of land, besides being partly evaporated and partly absorbed, has further a natural tendency to gravitate in the direction of the rivers and streams, which form the natural ducts or channels for carrying the rainfall back to the ocean, its original source. It is this portion, when on its way to the natural streams and water-courses, that is made use of in works of this character, and which are so constructed as to intercept the rainfall, either before it reaches its natural course, or, in some cases, after it has arrived in its natural channels, and to convey it to large impounding reservoirs, where it is stored in sufficient quantities for use as required.

Supplies taken from drainage, or collecting areas, or gathering grounds (as they are sometimes called), are by no means uncommon in this country, in conjunction with works for the supply of water to towns, and also for utilising the rainfall for mechanical purposes. Works of this description are not of modern origin, but have been in use in past ages in many countries. A portion of the water supply of ancient Jerusalem, as mentioned by Dr. Whitty and others, was furnished in this manner, as a large drainage area contributed to supply the Pools of Solomon with water—in fact, these pools are reservoirs formed like those of many modern works, partly by throwing an embankment across a valley, and partly by excavation. The contents of the three pools, as given by Dr. Robinson's measurement, are as follows:—First pool has a capacity of 1,634,475 cubic feet; second, 2,536,414 cubic feet; third, 3,873,937 cubic feet; making a total capacity of upwards of 50,000,000 of gallons. These pools are arranged in the incline of a valley, the smallest being the highest, and the largest the lowest pool. As the second pool is only 160 ft. from the first, and the lowest but 248 ft. from the second, it is quite clear that a much larger reservoir might have been made by carrying up the embankment of the lowest reservoir to a greater height; but the probability is, it was not done as a measure of safety, for the additional depth of water would have added immensely to the risk of damage; and, indeed, the extreme care and caution which seems to have

Digitized by Google

marked all the early hydraulic works is by no means a bad example to follow. The gigantic reservoirs of Egypt, for storing the waters of the Nile for utilisation, are ancient examples of works of this nature, and are of so stupendous a character, and of so remote a date, as to perplex and confound historians, many of whom have classed them with natural formations. But, as Ewbank observes, all ancient writers unite in asserting that Lakes Nitocris and Mœris are the work of men's hands. China also contains many traces of the early development and high state of mechanical and hydraulic science; and vast reservoirs, for containing water for the supply of canals, for agricultural and commercial purposes, are not at all uncommon there.

The care and skill of the Romans is shown, amongst other works, in those of this character, for the supply of water to the cities and towns under their dominion; indeed, it is a remarkable fact that, in nearly every country and land subjugated by their arms, the remnants of their handiwork and skill are still to be seen. In many instances the benefits they conferred upon the past generations are still felt by the present generations occupying those countries. Works executed by them of the nature of collecting supplies from drainage areas are to be found in Spain, Egypt, and other places.

Like every other source of supply there are many circumstances to be considered in constructing works for procuring water from drainage areas, the principal of which are—the rainfall, character of the soil, natural configuration of the district, and the state of its cultivation. Having determined upon the amount of rainfall, which in all calculations for new works should be the minimum, we must next consider the various circumstances that tend to diminish it. We have already treated of these under the head of evaporation and absorption; but as each of these is more or less affected by the physical peculiarities of the district, we must carefully consider them. In every case where the surface soil is porous, a great portion of the rainfall will be absorbed; and in constructing works for collecting water from areas of this nature, it will be well to consider if, by suitable under drainage, a larger portion of the rainfall cannot be collected, which, under other circumstances, would sink deep into the ground, beyond the reach of works of this character. Again, it may sometimes happen that a porous soil overlies an impervious bed, when a large portion of the rainfall could be secured by under-drainage, or the formation of deep intercepting drains. Again, in places where the surface is quite or nearly impermeable, the formation of under drains will not add much to the quantity of water collected. It may then be taken by open channels, and the natural ones of the district will often

Digitized by Google

suffice. Open channels are, however, objectionable, because, in most soils, the channel must be of such size as to limit the velocity of the current to a speed not exceding half a mile her hour; otherwise, the bed will be worn and the water made turbid. This necessarily slow motion is attended by its evils, as it favours the deposition of silt washed from the surface of the drainage area, and is also favourable to the development of vegetable and animal life, and loss by evaporation. Open channels also form receptacles for vegetable matter which the wind may carry in.

In considering the physical peculiarities of the district, it must be borne in mind that, if the district is level and not intercepted with valleys, the expense of making impounding reservoirs, which, in all works of this character, are absolute requirements, will add immensely to the cost of such work; whereas, in districts traversed by valleys—often containing natural streams—impounding reservoirs can be more cheaply constructed by throwing an embankment across the ravine, and at once forming a natural reservoir. In computing the quantity of the supply likely to be furnished by drainage areas, it is well not only to consider what may appear the natural areas or slopes receiving the rainfall, but also the geological areas, in considering which the engineer must pay particular attention to the dip and direction of the strike of the strata, as it materially influences the flow of water. For instance, it often happens that the supply may be augmented by springs, when the dip of the strata is in the direction of the slopes of the drainage areas; while, on the other hand, the supply may be diminished by the facility with which the water may be carried away by an absorbent strata, having a dip in a direction opposed to the slope of the drainage area, as illustrated in Figs. 2 and 3. The position, form, and dimensions of the drains for conveying the water to the reservoir will, in all cases, depend upon the contour of the district; but in cases where covered channels are used, the excavation, after receiving the conduit or pipes, is often filled up with broken stone, in order to facilitate the entrance of rain and drainage waters.

In laying out works of this character, attention must be paid to the area of land enclosed by the catch-water and other drains; and, when practicable, the main conduit, that will encircle the collecting area at the lowest point, should be arranged at sufficient elevation to procure a fall, so as to enable the water to be distributed, without mechanical means being required to raise it, to give sufficient pressure.

Digitized by Google

Quality of Water taken from Drainage Areas.

In laying out works for the collection of water from drainage areas, it must be borne in mind that the nearer the actual rainfall water is collected the freer it will be from adventitious matter, and at the same time, in selecting drainage areas, it must be observed that purity of water and fertility of soil are never to be expected together. Water taken from drainage areas, where the substratum is peat, or from lands in a high state of cultivation, is objectionable; as in the former case many vegetable organic impurities will be present; while that taken from land in a high state of cultivation will contract and contain many organic and inorganic impurities. The best quality of water contributed by drainage areas will always be found in the barren districts of the primary geological formations, and in the moorlands on the sandstone rocks. Next to these, the water taken from pastoral districts will probably rank in purity, and that from cultivated districts will be the worst. In cases where the water is collected quickly from the drainage areas, and before it has had time to penetrate deep into the earth, it is comparatively pure; excepting in those cases of highly cultivated and manured districts. Water taken from some drainage areas supplied by covered drains will not be as chemically pure as water taken direct from the surface without being allowed to penetrate the strata; as when it penetrates the soil it may collect inorganic impurities.

Quantity of Water derived from Drainage Areas.

Illustrated in Plate 1, Figs. 2, 3, and 4.

The quantity of water capable of being collected from a drainage area depends mainly upon the geological formation and physical outline of the district. If the district is of an impermeable geological character, having steep slopes, a very large portion of the rainfall can be collected; on the other hand, if the geological character of the district is porous, and its contour flat, as in some sandy and chalky districts, very little or no water could be depended upon from works of this character; and, as the geological character of a district approaches one or the other of these conditions, so will the per-centage of the rainfall capable of being collected fluctuate. The engineer, in constructing works deriving supplies from drainage areas, must take into consideration the amount of water capable of being yielded by springs flowing in the areas, as it may occur that the rain falling on a porous part of the district may make its appearance again

Digitized by Google

at another point in the form of a natural spring. As has been already mentioned, if the surface of the drainage area is porous, resting on impervious strata, a much larger quantity can be obtained by under-drainage than if the water was taken from the surface only. The quantity of water capable of being taken by under-drainage, if the strata is uniform, will depend upon the depth of the drains. An experiment made by Mr. Milne, of Milne Garden, in Berwickshire, extending from June, 1848, to April, 1849, shows that under-drains 3 ft. deep, laid 15 ft. apart, gave nearly 36,000 gallons per acre; while drains laid $3\frac{1}{2}$ ft. deep and 20 ft. apart, gave at the rate of 47,000 gallons per acre, which was about one-tenth the rainfall of the district. It is clear from this experiment that a considerable portion of the rain descending on the surface, either ran off at the time of the rainfall, and consequently did not penetrate to the depth of the drains, or it passed below them and out of reach of their action: in every porous soil a large portion of the rainfall could not be collected by drains placed a distance apart, as the water would penetrate deeper than the drains. From observations of some of the various works constructed for the supply of water from drainage areas, the amount of water taken and used varies from one-sixteenth to over two-thirds the rainfall of the district, as will be seen from the following examples of works in operation; but many of the works could probably supply a larger quantity, as the quantity given is the amount absolutely used. There can be no doubt that if the surface of every drainage area was, or could be made, impervious, and sufficient slope be given to it to carry off the water quickly, a very large per-centage of the rainfall might be used. But the great drawbacks to making the surface that should receive the rainfall impervious are—first, the expense; and, secondly, the restriction it would put on agricultural pursuits. The expense of making a surface impervious has been estimated by Mr. Hughes at 242*l*. per acre, which price would exceed the value of the water that would be collected from it, so that if this system had to be put in operation at the present prices paid for water, it would not pay. The sufficiency of the rainfall to furnish a supply of water may be derived from the fact that if two-thirds of the rainfall of England and Wales could be collected, it would furnish a supply to each individual of the population of a quantity exceeding 2500 gallons per day; but the rain falling on the sites of our cities and towns would not be sufficient for a supply according to the present rate of consumption. For example, the most crowded parts of London are peopled at the rate of one person to every $12\frac{1}{2}$ yards; now, taking this area with a rainfall of 24.8 in., if two-thirds of it could be collected, it would furnish 2.63 gallons per head per day. In the

Digitized by Google

City of London one person has 40¼ yards area, which with the same rainfall and at the same rate would furnish 8.54 gallons per head per day. Although in a great place like London it would not be possible to utilise the quantity given, and the quality would not be the most desirous, yet for many purposes the quantity of rain falling upon the sites of our cities and towns, if utilised, would tend much to our advantage.

Examples of Waterworks supplied from Drainage Areas.

Ashton, in Lancashire, is supplied from a collecting area of 378 acres on the millstone grit formation. The rainfall of the district is 40 in., and .384 of the rainfall is stored.

Belfast, in Ireland, is supplied from a drainage area of 980 acres. The supply is taken by open channels, and stored in reservoirs capable of containing ninety days' supply, at the rate of 102,000 gallons per day. With a rainfall of 32 in., .522 of it is used.

Bolton, in Lancashire, is supplied from a drainage area of 1041 acres, situated on the millstone grit formation. The supply is taken by covered channels, consisting of pipes laid in trenches, covered with gravel, and the trench then sodded over. The water is stored in a reservoir capable of containing ninety days' supply, at the rate of 2,000,000 gallons per day. The rainfall of the district is 50 in., and .619 in. of it is used.

Dublin New Works are supplied from the river Vartry, which has a drainage area of 14,000 acres, and with a rainfall of 45 in. and 20,000,000 gallons of water daily supplied. .500 of this will be used. The supply is stored in reservoirs capable of containing 120 days' supply.

Dukinfield, in Cheshire.—These works are constructed to be supplied partly from a drainage area of 383 acres, situated on the millstone grit formation, and partly by meter from the Manchester Waterworks. With a rainfall of 36 in., it is found that about one-half is stored and used. The water is taken from the land in both open and covered channels.

Glasgow is supplied with water from Loch Katrine, which has a drainage area of 43,000 acres, on the silurian formation, which supplies Glasgow with 23,000,000 gallons daily, besides 40,000,000 gallons daily, as compensation to millowners. 130 days' supply is stored; and with a rainfall of 60 in., .402 of it is used.

Greenock is supplied from a drainage area of 5043 acres. With a rainfall of 60 in., .603 of it has been observed to run off into the reservoirs.

Digitized by Google

Huddersfield, in West Yorkshire, is supplied from a drainage area of about 1000 acres, situated on the millstone grit formation. The supply is taken by covered channels, and 120 days' supply is stored, which, besides supplying 500,000 gallons of water per day to the town, gives a large quantity of water as compensation to millowners. With a rainfall of 33 in., .537 of it is stored and used.

Liverpool is partly supplied from wells, but principally from a drainage area of 10,400 acres, contributing to Rivington Pike. A supply of 120 days is stored, and with a rainfall of 55.5 in., .436 of it is stored.

Macclesfield, in Cheshire, is supplied from a drainage area of 2000 acres, situated in the coal measures. The supply is taken by covered channels, and stored in a reservoir capable of containing forty days' supply. With a rainfall of 40 in., .526 of it is used.

Manchester is supplied from a drainage area of 18,900 acres on the millstone grit formation, which furnishes a supply of 12,000,000 gallons per day, to a population of 550,000, and 55 cubic feet of water per second for twelve hours daily, as compensation to millowners. With a rainfall of 37 in., .617 of it is actually used, while from Mr. Bateman's evidence it appears that nearly three-fourths of the rainfall can be made available.

Oldham, in Lancashire, is supplied from a drainage area of 2700 acres, situated in the coal measures, which furnishes a daily supply to the town of 1,600,000 gallons, and 219 cubic feet of water per minute for twelve hours daily, as compensation to millowners. With a rainfall of 35 in., .415 of it is used, and six months' supply is stored.

Paisley is supplied from a drainage area of 790½ acres, situated on the coal measures. The supply is taken by open channels, and 200 days' consumption is stored. From a recent report of W. R. Copeland, the engineer, it appears that during the last year, with a rainfall of 56.33 in., .548 of it was used; but the amount capable of being supplied he takes at 84 per cent. of the rainfall, as he allows but 16 per cent. for loss by evaporation and absorption.

Plymouth, in Devon, is supplied from a drainage area of 4000 acres, situated on the granite hills of Dartmoor. The supply is taken by open channels. With a rainfall of 44 in., .343 of it is used for town purposes.

Preston, in Lancashire, is supplied from a drainage area of 3000 acres, in Longridge Fells. The supply is taken both by open and covered channels, and 150 days' consumption is stored, with a rainfall of 43 in., but .232 of it is used.

St. Helen's Old Works are supplied from a drainage area of

Digitized by Google

280 acres, situated on the coal measures. The supply is taken by both open and covered drains, and is stored in a reservoir capable of holding 125 days' supply. With a rainfall of 30 in., .122 of it is stored and used.

Southampton is partly supplied from a drainage area of 120 acres, situated on the Eocene formation. With a rainfall of 23 in., one-third of it is collected.

Wigan, in Lancashire, is supplied from a drainage area of 2200 acres, situated on the coal measures, which furnishes a supply of 600,000 gallons per day to the town, and 800,000 gallons per day as compensation to millowners. The supply is taken by open channels, and 180 days' consumption is stored. With a rainfall of 40 in., .26 of it is used.

WATER SUPPLY TAKEN FROM RIVERS AND STREAMS.

The water taken from rivers and streams is supplied by drainage areas of large extent. The distinction to be drawn between works deriving supplies direct from drainage areas, and from rivers that receive their supplies from drainage areas, is this: In the case of drainage areas all the water of a particular district is dealt with, while in the case of rivers a proportion only of the water of a much larger district is taken. When all, or a large per-centage, of the water of a river or stream is required, such works may be classed with those taking supplies from drainage areas, and will require the storing reservoirs and appendages of that class of works, as is the case with the new Dublin waterworks. Generally the water of rivers consists of water falling upon the various geological strata, from some of which it flows off directly; while from others it flows after penetrating to various depths, and issuing in the form of springs; consequently, the quality of river water is subject to greater variation than that collected from a limited drainage area, and is, in fact, a sort of mean between the waters of many sources.

The flow from some rivers and streams is subject to great variation, as streams that take their rise in mountainous districts, or which run over impervious formations, are often subject to freshets, while at other times these channels may be nearly, or quite dry. It is found that the more impermeable the district, the more rapidly the streams swell and the rainfall is run off; whilst in permeable districts the soil retains the water and parts with it more slowly. Hence rivers flowing through such districts are not subject to such extreme variation of floods or droughts as those flowing through strata of a more impermeable character. The quantity of water flowing off by rivers and streams varies

Digitized by Google

with the season of the year, and the physical and geological nature of the district from which the water is derived, or over which the river flows. The discharge of water from rivers is not always proportional to the watershed, but depends more especially upon the geological character of the district, the amount of the rainfall, and the seasons of the year. The proportion between drainage and rainfall varies in different localities. Experiments made in 1835 upon drainage areas in Eatonbrook and Jamidson brook valleys in the state of New York, by J. B. Jervis, Esq., show that .449 of the total rainfall ran off by drainage. From tables compiled by Mr. Beardmore, C.E., the Thames at Staines carries away .119 of the rainfall of a district composed of chalk, greensand, Oxford clay, oolites, &c. The Loddon carries away .118 of the rainfall from a greensand district. The Nene, at Peterborough, draining a district of oolites, Oxford clay, and lias, carries away .081 of the rainfall. The Wandle, below Carshalton, draining a chalk district, carries away .414 of the rainfall. Mimran, at Panshanger, from the chalk, carries away .435 of the rainfall. Plym, at Sheepstor, from the granite, carries away .335 of the rainfall. Glencorse Burn, flowing from Pentland Hills, carries away .131 of the rainfall. The proportion of rain drained off by rivers is not so great as that which is intercepted and impounded in the reservoirs of some works constructed to take their supplies direct from drainage areas; the reason of which is that the water of rivers is exposed to circumstances favourable to the processes of absorption, evaporation, and animal and vegetable assimilation.

Although the proportional amount of rainfall conveyed away by a river is not so great as that which may be collected direct from a drainage area, nevertheless, the enormous drainage areas of rivers render them extremely useful for taking supplies of water, and it is worthy of note that the majority of the old-established cities and towns of this and other countries have been situated originally upon rivers and streams of various capacities, probably with a view to secure a sufficiency of water for various purposes, as well as on account of their forming a highway or road to facilitate the transit of their commodities, or as a protection and defence from their enemies.

One great drawback to the use of water for the supply of towns is its want of limpidity at particular seasons of the year, which necessitates the use of special measures for its purification. This want of limpidity is owing to the currents of water wearing away the sides and bed of the channel, or conveying the detritus washed from the surface of the land from which it may flow. The mechanical matter thus conveyed by rivers may be divided into two varieties—viz. that which is suspended in the water, and

Digitized by Google

that which it rolls over the bed of its channel by the mechanical force of the current. The amount of matter transported by a river under the latter circumstances depends upon the velocity of the water, the nature of the bottom of the channel, and the shape, character, and size of the particles moved. From experiments made by Bossut, Dubuat, and others, the size of particles conveyed by rivers flowing at different velocities is as follows:

Velocity per Second.	Materials conveyed by Stream.
3 in.	Fine potters' clay.
6 in.	Fine sand.
8 in.	Coarse sand—size of linseed.
12 in.	Fine gravel.
24 in.	Pebbles—1 in. diameter.
36 in.	Angular stones—size of an egg.

The way in which the particles of sand are transported by a river are interesting, and the examination of a sandy bed of running water presents a section of a series of undulations or inclined planes. The up-stream side of these planes is very gentle, while the down-stream side is steep. The grains of sand moved along by the water are forced up the long slope, and when they arrive at the top of the plane, fall down the steep side on to the foot of the next long slope of the undulations below, and so they are conveyed along; thus, in some measure, the rate of abrasion of the bed of the channel is diminished by this action. The matter that is urged along the bed of a channel by the current only influences works for the supply of water in cases where an accumulation of such matter has a tendency to choke or diminish the sectional area of the artificial channels or pipes provided for conveying it, against which provision must be made.

The quantity of matter held mechanically in suspension in the water depends mainly upon the velocity and specific gravity of the matter suspended. In all cases it will be found that the lightest matters are held longest in suspension; and in studying the physical condition of rivers it will be observed that, whenever any circumstances occur that have a tendency to reduce the velocity, a certain amount of the heaviest matters held in suspension will be precipitated; consequently, in rivers unaffected by tides, the lightest matter will be carried the farthest; and if precipitated, will be deposited at the outfall. The following table gives the proportional quantities of matters suspended in some river waters:

Digitized by Google

Name of authority.	Name of river.	Proportion by volume.	Proportion by weight.
T. Logan, C.E.	Irrawaddy—flood.	$\frac{1}{3984}$	$\frac{1}{1511}$
Do.	" ordinary state.	$\frac{1}{11379}$	$\frac{1}{5762}$
Mr. Ellet.	Mississippi (mean)	$\frac{1}{3000}$	$\frac{1}{1611}$
Mr. L. Horner.	Rhine—flood.	$\frac{1}{24949}$	$\frac{1}{12500}$
Do.	" ordinary state.	$\frac{1}{41888}$	$\frac{1}{20734}$
Do.	" mean.	$\frac{1}{31104}$	$\frac{1}{15598}$
Sir George Staunton.	Yellow River, China.		$\frac{1}{300}$
——	Seine—flood.		$\frac{1}{2000}$
B. Latham, C.E.	Ouse* at Ely—flood.		$\frac{1}{23548}$
Do.	" minimum.		$\frac{1}{888000}$
Do.	" mean.		$\frac{1}{119858}$

There are so many circumstances connected with the presence of the mechanical matters held in suspension, that no general rule can be laid down as to the amount that may be expected under certain conditions; yet there are some known circumstances, such as increase of velocity, that favour the acquisition and transportation of such matter. The corroding and abrading action of water is incessantly re-arranging the strata of the earth's crust, and geology teaches us that the same results that are now being produced by the flow of our rivers in conveying the particles of various geological strata from elevated localities to the valleys or the mouths of our rivers have been in active co-operation for countless ages.

Quality of River Water.

The quality of the river water varies immensely with the character of the district drained, and some river waters, after being freed from the adventitious mechanical matters present, are of great purity, such, for instance, as the waters of some of the rivers of Switzerland, Scotland, Wales, and the north of this country. It has been already mentioned that the quality of

* The amount of matter suspended in the water of the river Ouse, at Ely, is based upon the daily observations of the author, extending over a period of eight months. These observations are tabulated in Plate 2. W.W. shows the height of the water above the datum on the river gauge. The line M.M. shows the impurities; the fine horizontal lines represent the height of water in feet, and also the amount of impurity, as one foot of water in the diagram is made to represent one-tenth of a grain of suspended matter. This diagram is interesting, as it shows to the eye at once the effects produced by an increase of water in the river, as connected with every rise of water there was found to be a corresponding increase in the amount of mechanically suspended matter present in the water.

Digitized by Google

river water is a mean between the waters of many sources; the nearer the water supply is taken to the rise or head the purer and freer it will be from organic impurities. Rivers taking considerable supplies from permeable districts, into which the rainfall percolates the strata to various depths before arriving at the river, will contain a larger amount of inorganic matter than rivers deriving their supply from the surface drainage of impermeable districts. River water, as a rule, contains a large amount of organic matter, consisting of minute animal and vegetable organisms, as well as of the matter acquired from the decay of vegetation and from the surface of cultivated lands, and in many instances from the reprehensible plan of turning the sewage of the towns situated upon its banks into the stream. There can be no doubt that a marked improvement would take place in the quality of many rivers if compulsory powers were enforced to prohibit the obnoxious contents of sewers and cesspools being turned into the rivers, which under other circumstances, if properly applied, can be profitably utilised.

River water, taken at points removed from the centres of great populations, or from highly cultivated lands, is often very good in quality, and, being generally well aërated, is highly esteemed; the great drawback to the use of it is the variableness of its quality and temperature. These matters, together with the various modes of purifying river water, will be considered hereafter; but the following table gives a list of the impurities present, and the analysis of the water of some rivers:—

Digitized by Google

Name of river and authority.	Carbonate of lime.	Sulphate of lime.	Carbonate of magnesia.	Sulphate of magnesia.	Chloride of magnesia.	Sulphate of soda.	Carbonate of soda.	Chloride of sodium.	Sulphate of potassa.	Nitrate of potassa.	Nitrate of soda.	Nitrate of magnesia.	Phosphates, earthy.	Alumina.	Oxide of iron.	Silicic acid.	Organic matter.	Total.
Clyde, Penny......	2.52	.26	.72	...	.40	1.94	...	.54	1.94	...	...	...	.31	.28	Trace	.28	.89	7.86
Severn, do..........	.50	.52	...	...	.66	.39	...	.73	.39	...	...	...	.18	.32	...	.32	.45	3.75
Seine, Deville......	11.609	1.886	.189	Trace	...	...	...	.862	.35	...	.659	.364	...	.035	.175	1.711	...	17.84
Rhine, do.	9.511	1.03	.350	...	...	.946	...	.14	...	2.66	...	...	...	.175	.406	3.423	...	16.247
Garonne, do.	4.524	...	.238	...	...	.371	.455	.224	.533	...	...	...	...	...	.217	2.813	...	9.585
Loire, do.	3.374	...	.427	...	...	.238	1.423	.336	...	...	...	...	...	.498	.385	2.848	...	9.437
Rhône, do.	5.334	...	3.43	...	...	.519	...	.119	...	.28	.315	...	.333	...	...	1.669	...	9.082
Doubs, do.	13.397	...	.161	...	.035	.357	...	.161	...	.287	.273	...	...	.147	.21	1.114	...	16.142
Thames, Letheby .	11.10	4.78	...	...	...	.48	...	1.88	...	...	...	...	...	.76		1.0	2.75	22.75
Ouse (Ely), do. ...	13.0	10.39	...	...	.37	1.01	...	2.50	...	3.40		...	...	.67		.12	1.34	32.8
Lea																		23.7
Colne																		21.3
Trent	.32	21.55	5.66	...	...	...	...	17.63	...	...		...	Trace	.50		.72	3.68	50.16
Dee..................	.85	.12	.36	...	...	...	...	.72	...	...		...	Trace	.06		.14	1.64	3.89
Don..................	2.23	.13	1.07	...	...	...	...	1.26	...	...		...	Trace	.27		.52	3.0	8.54

The following is a list of some of the towns of this country that derive their water supply from rivers and streams :—

Name of town.	Quantity of water used daily.	Name of river or stream.
Banbury..................	120,000 gallons	River Cherwell
Barnstable...............	120,000 „	A brook
Carlisle...................	1,000,000 „	River Eden
Chester...................	900,000 „	River Dee
Dublin.....................	12,000,000 „	River Vartry
Durham	350,000 „	River Weir
Ely	300,000 „	River Ouse
Exeter	960,000 „	River Exe
Hereford	220,000 „	River Wye
Ilfracombe...............	30,000 „	A stream
Leamington.............	300,000 „	River Leam
Leek	200,000 „	A stream
Lynn	1,000,000 „	Do.
Middlesborough and others..................	———	River Tees above Darlington
Newark...................	150,000 „	River Trent
Penrith...................	300,000 „	River Eamont
Perth......................	250,000 „	River Tay
Southampton............	1,800,000 „	Partly from river
St. Thomas the Apostle	90,000 „	River Exe
Stockton	———	River Tees
Torquay..................	360,000 „	Dartmoor
Wakefield................	400,000 „	River Aire
Wellington	———	Wrekin Brook
Wolverhampton	1,250,000 „	River Worf
York	1,306,000 „	River Ouse

Digitized by Google

December 5th, 1864.

J. GLYNN IN THE CHAIR.

UPON THE SUPPLY OF WATER TO TOWNS.

(SECOND SECTION.)

BY BALDWIN LATHAM.

SUPPLY FROM NATURAL SPRINGS.

IT has been already observed that many rivers receive a portion of their supply of water from springs; consequently, those towns which use the water of rivers are literally deriving a supply partly from springs and partly direct from drainage areas—for the permanent flow of a river is due to its receiving large accessions of water from springs. It may sometimes occur in practice that a spring itself may be taken advantage of to furnish a supply of water; or if the natural flow of water from such spring is insufficient of itself, yet, as it may indicate the source of a more copious supply, no paper on water supply would be complete without an inquiry into the theory of springs.

It has been shown that the amount of rain falling on elevated localities is more than on low table-land; the flow of water from springs is due to the rainfall that has been absorbed by the porous strata of the highlands of a district into which it percolates, until intercepted by some impervious bed of strata, by which it is retained in the porous strata, and compelled to traverse it in the direction of its inclination, until at length it may make its appearance at the surface of the ground at a point somewhat lower than that at which the meteoric water was received. The power that impels the rain through the porous strata is hydrostatic pressure, which in some measure is modified by the friction and the capillary attraction of the strata through which the water flows. Springs are kept constantly flowing, by repeated rainfalls and the modifying influences of the strata already mentioned. The permanency of a spring is consequently closely allied to the character and extent of the strata through which the water may flow. If the strata is of an open or porous character, and of but small extent, the springs flowing from it will vary much in their delivery, and will, in all probability, become intermittent in their flow. If, on the other hand, the

Digitized by Google

strata is moderately porous, and of large extent, springs yielded by it will generally be large and permanent. Of such may be said to be the springs flowing from the chalk or greensand formations. Springs may be divided into classes, each class depending upon the relative position of the strata with respect to the discharge of the water, and acquirement of the meteoric water. The first class may be called land springs (illustrated in Plate 1, Fig. 6), and are found in those places where a superficial strata (as sand or gravel) of moderate thickness covers an impermeable strata; a natural flow of water will take place if there is a dip in the strata, and at the lower outcrop springs of this class will appear, but owing to the limited area of the strata they are generally of an intermittent character, as they depend directly upon the rainfall to keep up the flow. Closely allied to this class is another, consisting of porous strata of great extent and depth, from which the water flows as in the preceding case. Of this class may be said to be the chalk springs in some districts, and which, owing to the great extent of their area, act as immense reservoirs to store the water, which is pretty uniformly liberated, owing to the friction of the water in passing through the strata, and the attraction the strata itself exerts, which retards the speedy escape of the water. Another class of springs (illustrated in Plate 1, Fig. 7) may be described as those flowing from a porous strata. Lying between beds of a more impermeable character, springs of this class make their appearance at the outcrop, or through any fault in the open impermeable strata; but inasmuch as they receive their supply of water only at the basset of the strata, which is generally of a limited area, springs of this description cannot often be depended upon to furnish a large or permanent supply of water. Another description of spring (illustrated in Plate 1, Figs. 8 and 9) may occur by reason of a fault or intervention of an impervious dyke when a permeable strata overlies an impermeable. The volume of water yielded by springs of this nature is often great, owing to the interception of the body of water flowing through the strata. The constancy of a spring depends upon the extent and character of the strata, combined with the rainfall. The flow of springs that are intermittent has been shown to arise from the limited extent and the porosity of the strata. The flow from springs may also fluctuate, owing to the formation of the porous strata; thus, if the porous strata is so disposed as to constitute a reservoir, with a sort of syphon arrangement for its discharge, the action of such spring will be intermittent. The limpidity of water flowing from springs, and the elevation at which they are often found, renders them, under certain circumstances, extremely valuable in furnishing supplies of water, and they have been made available, in

Digitized by Google

many instances, for the supply of water to many towns, both in this and other countries.

London, prior to the construction of the waterworks at London Bridge, near the end of the sixteenth century, was partly supplied by springs which were conveyed into the city by lead and earthenware pipes, principally at the cost of different Lord Mayors, and the munificence of some wealthy citizens.

The gigantic scheme of supplying London with water from the springs at Chadwell and Amwell, which, by the instrumentality of the New River Company, was realised on the 29th September, 1613, forms a striking example of the utility and copiousness of some springs for furnishing a supply of water to towns.

Springs have not only been made available in this country, but also in others; and at periods in history far more remote than we can boast of in this country, have works of magnitude been constructed for conveying the water from distant sources into numerous cities and towns.

Spring water has the advantage of issuing from the earth at nearly always the same temperature, and on this account is commendable. In making calculations for the supply of water from springs, it should be borne in mind that the volume should always exceed the maximum demand, and if the springs are of such a character as to fluctuate in their flow, so that the entire yield may be sufficient, or in excess of the entire consumption or demand, it may be advisable, if not absolutely necessary, to store the excess of water in impounding reservoirs for use during the periods of limited supply, in which case the quantity to be stored will depend upon the rate of fluctuation of the flow.

Quality of Spring Water.

The quality of spring water varies considerably; but, as a rule, the quicker a spring is affected by the rainfall (all other circumstances being equal) the purer will that spring be. The water furnished by land springs is generally of an impure character, as it is contaminated by the impurities of the surface, which are to some extent mineralised in passing through the strata.

All spring water contains more or less mineral matter, which they acquire during the process of infiltration through the pores of the strata. A very small quantity of this exists in mechanical suspension, being chiefly held in solution by the action of chemical agencies. The principal agents that render the strata so readily soluble are the acids and alkalies, which combine with

Digitized by Google

the ingredients composing the strata of the earth, and form compounds readily soluble in the percolating water. The value of spring water for domestic purposes depends upon its freedom from the compounds of earthy salts, and from organic matter; and in making choice of a supply, if the springs of a locality are found to contain a much larger per-centage of foreign matter than a source that may be made available at a somewhat greater cost in the construction or working expenses, it may be economy to abandon the near spring for another source. This selection of the source often furnishes a nice point for the engineer to decide, but there are certain well-defined points bearing upon the quality of water procured from various sources that will be considered hereafter, which should be the guide of the engineer in making his selection.

Wells.

The art of well-sinking is common to all countries, and was probably one of the earliest artificial means adopted to furnish a supply of water. From the earliest periods of history the records of both sacred and secular writ go to prove that the art was pursued alike by the savage who roamed the desert, and the citizen who inhabited the town; yet it should be here observed that there is a marked difference between the mere hole the savage may scratch in the sand, and the highly finished wells of some Eastern cities. So ancient are wells, that Ewbank observes they must have been of antediluvian origin; and that such useful works remain long after the destruction of those more splendid edifices that have been erected, more for the glory than the usefulness of mankind. The buried cities of Nineveh, Herculaneum, and Pompeii, abound in wells of excellent construction, containing good water, and which at the present day supply the inhabitants living in those localities. It is probable that the first wells were shallow holes excavated in the loose soil in moist places, such as are found at the present day to be executed by uncultivated or uncivilised nations or tribes. After the discovery of the metals, which is supposed to have taken place in the seventh generation, as Ewbank observes, rock and indurated strata no longer offered an impediment to the well-sinker, and, consequently, wells were sunk to greater depth in such strata. As the art of well-sinking developed itself at an extremely early period, and long anterior to the commencement of history, no very great advance has been made in it; indeed, the mode usually adopted at the present day when sinking wells to a great depth in loose strata, by first forming a curb on which the ordi-

Digitized by Google

nary steining is placed, and which settles down as the work of excavation is carried on within, and thereby preventing the loose soil falling into the well, was practised ages ago in sinking wells in the East, and from them we have copied the mode in more modern times. Wells of excellent construction abound in Hindostan, China, Japan, Tartary, Egypt, and elsewhere. When the British took possession of Hindostan, the number of wells in use in that country was estimated at 50,000. Many of the ancient wells were of great depth. The wells of Cabaul are from 300 ft. to 350 ft. deep, and many of them are but 3 ft. in diameter. The famous well at Tyre is said to be 630 fathoms in depth. Jacob's well at Samaria is 105 ft. deep, and 9 ft. diameter. The well Zem-Zem, at Mecca, is 210 ft. deep, and that of Joseph, at Cairo, 300 ft. deep. The well of Joseph (Plate 3, Fig. 1) is a fine example of the skill and boldness of design of the well-sinker. Although called after Joseph by the Arabs, it is by no means of so ancient a date as the name would imply, for the well was probably sunk about 700 or 800 years ago, but by whom is a disputed point; some attributing it to a Vizier of the name of Joseph, others to Saladin, the intrepid defender of his country, whose name was Yussef (Joseph). The well consists of two shafts, one above the other, but not in the same vertical line. The upper shaft is an oblong excavation 24 ft. by 18 ft. and 165 ft. deep, descending into a large and capacious chamber, in the floor of which is constructed a basin or reservoir for containing water that is raised from the lower shaft. In this chamber a lower shaft is sunk, which is an excavation 15 ft. by 9 ft. and 130 ft. deep. Round the upper shaft a spiral passage, 6 ft. 4 in. wide and 7 ft. 2 in. high, is cut, separated from the well by a partition wall of the solid rock, only six inches in thickness, through which loopholes are pierced for lighting the passage. This passage is made use of by parties who draw water, and also for the descent of mules or other animals that are employed in the large chamber below, to give motion to a system of chain-pots by which the water is raised from the lower shaft and poured into the basin in the chamber. There is also a spiral passage round the lower shaft, but it is not enclosed from the well as in the case of the passage round the upper shaft. The water of this well is procured from a bed of gravel after penetrating the strata to the depth before mentioned. Wells are common in Greece, and in the olden times of its classic glory were the places of public resort; just as in modern times men congregate at their clubs and such-like places, so did the sage Athenians meet together at their wells, and at them orators declaimed, and music and dance lent their charms to make them places of pleasure and amusement.

Digitized by Google

The Romans had a clear knowledge of the art of well-sinking, and wells executed by this people are found in every country they once possessed. Many of the successes of their arms were due to their knowledge in this branch of engineering, as when every other source of water failed or was cut away by their enemies, they had recourse to well-sinking to obtain their supply. It was the knowledge of well-sinking that enabled Cæsar to retain Alexandria when all the water of the cisterns had been spoiled by the Egyptians. The same knowledge enabled Pompey to procure a supply of water when holding a position of great advantage against Mithridates, who had abandoned it for want of water. Imperial Rome (prior to the time of Appius Claudius) was supplied with water principally from wells.

The water procured from wells is rain that has descended by the minute interstices of the earth's crust, and is stored in the numberless interstical spaces of a porous strata.

Wells may be classified under two heads—viz. *Ordinary Wells*, or those sunk into permeable or water-bearing strata, and *Artesian Wells*, or those sunk or more generally bored through impermeable strata until a water-bearing strata is tapped, when the water is forced upwards by virtue of the hydrostatic pressure due to the superior level at which the meteoric water was received.

Ordinary Wells may be again classed under the respective heads of *Shallow* and *Deep Wells*. The water from both classes is procured under precisely the same circumstances, but differs often very materially in quality and quantity.

Shallow Wells include ordinary domestic wells sunk a few feet into the permeable strata of the earth's crust, and, owing to their shallowness generally, only catch the adjacent percolating water, consequently cannot be depended upon to give a large supply; and, inasmuch as they are generally contaminated with the contents of sewers and cesspools when sunk in the superficial deposits under cities and towns, which are honeycombed with such offensive receptacles, or tunnelled with imperfect and leaking sewers, their waters are not to be recommended for general use.

Deep Wells sunk into permeable and water-bearing strata derive their supplies from a more remote and extensive drainage area brought into action by the depth given to the wells, the quantity of water yielded by them is limited by the friction of the water in passing through the interstical space and the molecular attraction of the strata for retaining the water, which practically limits the area draining into the well.

Artesian Wells have ages ago been in use, and the antiquity of boring wells of this class is so great, that the precise period of

Digitized by Google

their introduction is unknown. They are common to Syria and Egypt. China abounds with them, many being upwards of 1800 ft. deep and but 6 in. diameter. They are common in Italy and France; and in the province of Artois, of the latter country, they are so abundant that one may be found at nearly every door; and it is from this province that the art of sinking or boring such wells came into this country, and they are named by us after that place. Artesian wells are artificial springs, and the same remarks that apply to springs will apply to Artesian wells.

The quantity of water yielded by wells cannot be absolutely computed, as it is dependent upon so many varying circumstances; but in considering this part of the question we must have regard to the area of drainage, the nature of the stratum, its dip, strike, faults, absorbent properties, and the nature of the underlying and overlying strata, the rainfall, and the depth of the well itself.

The theory of the probable quantity of water yielded by wells is called the cone theory; *i.e.* the drainage area contributing to the supply of a well is represented by an inverted cone, the apex of which is at the bottom of the well, so that if the strata were perfectly uniform, and the flow through it equable, the quantity yielded by wells sunk to various depths would be represented by the area of the different cones; but inasmuch as perfectly uniform strata of any great extent is rarely met with in nature, it is impossible to lay down any but general laws in studying the probable yield of water by wells.

Physical Properties of the Strata.—The yield of water from a well depends upon the nature of the strata; thus, if the strata is of a close texture having but few and small interstical spaces, the drainage area is limited by the friction of the water in flowing through it, and by its capillary attraction; consequently in strata of this character the area contributing to the supply of a well will be represented by an inverted cone of acute angularity; while on the other hand, if the strata has large and numerous interstical spaces, it will yield water rapidly, and the area contributing to supply such well becomes practically infinite. And just in proportion as strata approach one or other of the descriptions of the strata mentioned (all other things being equal), so will the supply of water capable of being procured from wells sunk into them vary. The construction of a well will also influence the flow of water, as, for instance, when a well is sunk into dense but permeable strata containing much water, naturally yielding it slowly owing to the fineness of the interstices; by special arrangement an increased supply could be procured; these arrangements consist generally of long tunnels or headings,

Digitized by Google

driven or extended horizontally, sometimes to great distances from the shaft. They have the double advantage of not only offering a greater surface to allow of the escape of water into the well, but they also act as reservoirs for storing it, which is a great advantage in all cases, but more especially when the water is required at intervals and not continuously. Theoretically, the effect of tunnels or adits is the same as produced by deepening the well; as, according to the cone theory, the space included in the drainage area between the bottom of the well and the surface of the ground, represents the frustrum of a cone; consequently the same drainage area contributes to supply a well with adits as would supply a much deeper well without adits, as the apex of the cone representing the drainage area in the case of a well with adits is at a point lower than the actual bottom of the well. The nature, character, and position of the water-bearing strata, from which wells derive their supplies, must be carefully considered by every person who desires success to crown his labours in practising the art of well-sinking. It has been already shown, under the head of absorption, that the quantity of water sinking deep into the ground is influenced by many circumstances, and is not alone dependent upon the character of the strata; yet it is quite obvious to the most casual observer, that the nature of the strata has the most important bearing upon the quantity and quality of water yielded by wells; thus chalk, from its absorbent nature, has been found by observation on the steep chalk hills around London to absorb a rainfall of two inches per hour; the red sandstone formation, under suitable circumstances, also absorbs rainfall very rapidly, while the more impervious strata absorb it but slowly. The dip or strike of the strata will also have an important bearing upon the amount of water yielded by a well, as it may occur that the natural inclination of the strata may be unfavourable to the yield of any great quantity of water in a particular locality, as shown in Plate 1, Fig. 7.

Faults have a material influence upon the flow of water in the subterranean passages of the earth, and, consequently, have much to do with the amount of water capable of being yielded by wells. The level of the water in the same strata when disjointed by a fault is no longer the same, but may vary considerably, as shown in Plate 1, Fig. 11, and it may also often happen that a well may turn out to be a failure owing to the near proximity of a fault cutting off and diminishing the drainage area. The careful study of the strata should always form an important point in considering the desirability of well-sinking, and the want of such study often entails failures which we ascribe to faults; but the probability is that with further insight and

Digitized by Google

clearer knowledge, many of these failures (which are rather the fault of the engineer than any fault in nature) would not arise. Water flowing in the bowels of the earth follows the same laws as water flowing on the surface of the earth, except when modified by some disturbing cause. The line of saturation, or the level at which water may be procured, varies in different strata, and is affected by various causes; thus the effect of continuous pumping in a district is to lower the water level of such districts. Generally the water level in strata has an inclination in the direction of its flow; thus it has been established by the Rev. Mr. Clutterbuck and others that the inclination of the line of saturation in the chalk in the north of London is 13 ft. per mile. In other places it varies according to circumstances; thus, it is not improbable that the flow of some intermittent springs is due to the elevation in the line of saturation, as in the Bourne at Croydon, which breaks out occasionally after very heavy and continuous rains. As a rule it will be found that in those districts in which the flow of water from springs, and the flow of rivers, is equable, or neither subject to excessive floods nor droughts, but is always discharging very near the mean flow, that wells sunk into the particular strata from which these rivers or springs derive their principal supplies will yield the largest quantity of water.

Quality of Well Water.

The character of well water is fixed by the geological strata through which it flows—for as the water is making its way through the bowels of the earth, sometimes travelling a considerable distance, it dissolves more or less of the materials of the crust of the earth in its passage, and becomes impregnated with the soluble portions; on this account, well waters are never perfectly free from foreign substances, volatile or solid, which impress upon the water its character. The water of shallow wells of towns is invariably impure, owing to the infiltration of decomposing matters, which may to some extent become oxidised and decomposed in passing through the soil, and the gases evolved, after further oxidation, combine with the materials it comes in contact with in its passage; which being rendered soluble by this means, add greatly to the impurities present in the water. Thus the shallow wells of towns invariably contain a large quantity of nitrates in solution; they also often contain organic matter in the shape of animalculæ and fungi, the presence of which, if not directly injurious, is indicative of the presence of other matter highly objectionable, if not prejudicial. Although the soil has great power in oxidising the most objec-

Digitized by Google

tionable matters before they enter the wells, it is by no means certain that the earth can retain this power for any length of time, especially as the sources of contamination are multiplied; indeed, there is ample evidence to show that this power of the soil is limited; as for instance, the cases mentioned by Sir James MacGregor, who relates that when the British army was in Spain 20,000 soldiers were buried in a short space of time in rather a small piece of ground, and the effect upon the adjacent wells was such that the troops who made use of the water of those wells were attacked with malignant fevers and dysentery. The water of deep wells is generally freer from organic matters than that of shallow wells, but it generally contains an amount of mineral matter. The waters of deep wells, on account of their freedom from organic matters, are generally very agreeable as drinking water, if of proper temperature, but for some purposes they are objectionable on account of their hardness.

COMPOSITION OF WELL WATERS.

	LONDON shallow wells.	ELY upper part of city.	ELY lower part of city.	BURTON on TRENT.	CROYDON.	BRAINTREE.
Carbonate of lime	30.50	25.10	37.50	15.51	15.41	2.40
Carbonate of magnesia	...	...	...	1.70	.61	11.30
Sulphate of lime	8.20	18.36	52.84	18.96	.58	
Sulphate of magnesia	...	...	...	9.95	...	.70
Chloride of magnesia	...	.18	2.61	...	...	
Chloride of sodium	12.30	10.88	44.90	10.12	1.51	44.00
Alkaline sulphates	14.70	16.97	24.37	7.65	1.03	
Alkaline nitrates	16.70	28.88	36.86	...	...	12.80
Iron alumina	1.10	.71	.84	.60	...	Traces
Silica	...	.14	.13	.79	.93	1.30
Organic matters	...	.68	.53	...	1.09	
Total	83.50	101.90	200.08	65.28	21.11	72.50

TEMPERATURE OF WELL WATERS.

The temperature of water taken from the bowels of the earth is somewhat higher than that of waters found upon the earth's surface. The rate of increase has been variously estimated: thus, Mr. Paterson, in a magazine published in 1839, states that the mean temperature increases in the case of eleven wells sunk in Scotland about 1 deg. Fahrenheit for every 48 ft. descent. M. Valferdin found that in some wells in Paris the rate of increase was 1 deg. for every 57 ft. descent. M. de Girardin found at

Digitized by Google

Rouen that the rate of increase was 1 deg. for every 37½ ft. of descent; and in another case 1 deg. for 55½ ft. descent; while careful experiments on the Artesian well at Grenelle give an increase of 1 deg. for every 59 ft. descent. The mean temperature taken from the above observations would give a mean result, showing that the rate of increase of temperature as we descend is 1 deg. Fahrenheit for every 52 ft. descent. Owing to this rate of increase in the temperature of water taken from deep wells, when the well is very deep and the increase in temperature very great, the water is totally unfit for many purposes, and this fact should be taken into consideration when deciding on a source of supply. The temperature of the water at the well of Grenelle, which is nearly 1800 ft. deep, is 81.81 deg. Hospitals and public baths have been heated with it.

Form of Wells.

Various forms of wells have been made at different times, and under varying circumstances, and in all ages. The square, oblong, ellipse, and circle have all been used with success. Such of the wells of the East as were executed in solid rock and without steining, are sometimes in the form of a square, sometimes oblong (as Joseph's well), and sometimes circular, but of all the forms the circle is the best. The ellipse can be used in some special cases with advantage, but for all practical purposes the circle is by far superior to any other form, as a well of this form can be bored or misered to great depth under water. It requires less steining than any other form or shape of well of equal area, and its form is the best for withstanding the lateral pressure of the earth, as a strain on a particular part is mutually sustained by the whole steining.

Materials used in the Construction of Wells.

The sides of wells require lining or steining (as it is termed) with some material that will prevent the loose strata of the sides of the excavation falling into the well and choking it. The materials that have been successfully used in this work are brick, stone, timber, and iron. Each description of material is suitable under certain conditions, while in other positions it is objectionable. Brickwork, which is universally used in steining wells in this country, not unfrequently fails in certain positions; as by reason of admitting impure water when such water is under great pressure, or from the work becoming disjointed

Digitized by Google

from settlement due to the draining of a running sand bed, or the collapse of the well. Stone of good quality, capable of withstanding compressive strains, is good in its way; but, inasmuch as it requires an immense amount of labour to fit it for its place, it cannot successfully compete with brickwork in the formation of wells, more especially as it has no merits superior to those of brick when used in such work; however, if in any locality, by reason of its cheapness, it can be used, care should be taken to select only such samples as contain a large amount of silica; indeed, in all cases it is a point of great importance in studying the nature of the materials used in the construction of wells, to select those which are likely to be the most durable, and at the same time preserve the purity of the water contained in the well; and this is best secured by silicious materials. Timber is objectionable as a material to be used in the formation of wells, on account of its liability to decay, and thus not only endanger the construction of the well, but likewise to some extent foul the water by such decay. It is very largely used under some circumstances, especially in the preliminary operations in sinking most wells. It is also successfully used in lining the shafts of the salt wells of Cheshire, and will continue entire in such a position for a great number of years, as the brine seems to have a tendency to preserve the timber and prevent its decay. Iron is of modern application, and is a material extensively employed in steining wells; and, as it possesses many advantages over materials ordinarily used, its use is likely to be much extended. It possesses all the qualities of a good material, insomuch as by its character it is capable of bearing great compressive strains, and of effectually excluding the influx of all such waters as it may be desirable to keep out, and is not liable to decay under ordinary circumstances. The author has known instances where recourse has had to be had to the use of iron cylinders, when it has been found that four or five rings of brickwork, set in the best cement, have failed to keep out brackish waters; and, if the original design had provided for the introduction of these cylinders, it would have reduced the cost of the well very materially.

The introduction of iron as a steining for wells, whether in the form of cast or wrought iron cylinders, under many circumstances, will always be attended with economy and success. The well-sinker of the present day has often, in executing his work, to contend with the presence of large volumes of water, which, under ordinary circumstances, must be got rid of by pumping; but, by the introduction of iron cylinders, which can be sunk under water by the aid of the boring tool and miser, the consequent expense of pumping is saved. It will be entirely a

Digitized by Google

matter of calculation whether or not they should be used; but generally, and when no special object is required to be fulfilled, brick steining is the cheapest; though when the strata is particularly treacherous it is decidedly the best to have recourse to iron. Iron cylinders are absolutely necessary in sinking through sand charged with water; otherwise, if there is a current of water produced, the sand flows with it into the well, which is objectionable, as the sand speedily destroys or injures the pumps —moreover, it is attended with a more serious evil, and that is, the draining of the sand undermines the superincumbent strata, which may lead to the destruction of the well itself, or any buildings erected over it. In some cases where cast iron has been used in wells and the shafts of mines it has been softened by the action of the water, and converted into a species of plumbago. This in itself is not any objection to the use of iron, but rather to the use of such waters that are affected by it if used for the ordinary purposes of water supply for which the well was sunk. If, on the other hand, the action takes place from the attack of water it is desirable to keep out of the well, wrought iron may be substituted with advantage in the place of cast iron, or other measures may be adopted to preserve it. It may be observed that it is but in few cases that this action upon the iron can arise, and, when it does, it is not in those districts in which we must rely upon wells for obtaining a supply of water.

Copper was one of the early materials used in lining the bore-holes of Artesian wells, but of late years iron has entirely superseded it in this branch of engineering.

Mode of Sinking Wells.

In sinking ordinary wells in loose strata, an excavation is made to such a depth as the strata will admit without falling in. A wooden curb is then placed in the bottom of the excavation, and the brick steining laid upon it, and when carried up to the surface, the work of the excavation is carried on; but the way in which it is now proceeded with depends upon the method adopted in extending the steining. If the steining is intended to be added below the curb, the earth is excavated flush with the interior sides of the well, so that the earth underneath the curb supports the brickwork above. When the excavation has been carried on as far as convenient, recesses are made in the earth under the previous steining, and in these recesses the steining is carried up to the previous work. When thus supported the intermediate portion of earth between the portions of brickwork carried up are cut away and the steining completed. By a suc-

Digitized by Google

cession of operations of this kind the well is sunk and the steining carried to the required depth. On the other hand, if the steining is added from above, the curbs are supported by iron rods, fitted with screws and nuts from cross timbers over the mouth of the well, and as the excavation is carried on below, brickwork is piled on above, and the weight of the steining will carry it down as the excavation proceeds, until the friction of the sides overpowers the gravitating force or weight of the steining, when it becomes, as it is technically called, earth-bound; then a set off must be made in the well, and the same operation repeated as often as the steining becomes earth-bound, or recourse must be had to the first method of under-pinning. Brick steining is executed either in bricks laid dry, or in cement; when the work is laid dry, a ring or two of brickwork in cement is often introduced at intervals varying from 5 ft. to 12 ft. apart to strengthen the work and facilitate the construction of the well. The bricks are laid flat, breaking joint; and to keep out moderate land springs, clay, puddle, or concrete, is often introduced at the back of the steining; for most purposes concrete is the best, as, in addition to its impervious character, it adds greatly to the strength of the steining.

The same measures are used in sinking iron cylinders as are adopted in sinking brick steining. Generally the cylinders are made of cast iron, either cast entire or built up of several shutters; the cylinders have internal flanges by which they are secured together, and which add very much to their strength; they are usually fastened together by bolts, and the joints are caulked with iron cement. Cylinders of this description, when they become earth-bound, can be driven so that they may be sunk to considerable depths without much trouble. The cast-iron pipes used in lining the bore-holes are put together with collars sunk into a recess at the ends of the pipes, or cylinders, and to which they are secured by countersunk screws, so that both the external and internal face of the cylinder is flush, and offers no impediment either to their being sunk or to the flow of water. When the supply is taken from sand it is usual to perforate the pipes, but this is not necessary in most strata; indeed, in the bore-holes in chalk and sandstone, or other strata that will stand without artificial support, it is not usual to line or stein except in cases where it is desirable to shut out some particular water.

Boring Wells.

The art of boring wells is evidently more modern than the practice of sinking, yet it is of so remote a date that the precise period of its introduction is unknown. Wells that have been

Digitized by Google

bored are common in China, Syria, and Egypt; and many of them are supposed to have been executed 4000 years ago. In France, the earliest authenticated well is at Lillers, supposed to have been executed in 1126. In boring wells two systems have been adopted: one is called the Chinese system, and consists in having the boring tool attached to a rope; the other is the ordinary method, in which the boring tools are attached to a rod of iron or wood. Although these are the two primary ways adopted in boring, there are many modifications of them in practice combining one or other method; indeed, every engineer or contractor may have his own particular mode, or the circumstances connected with each work may demand the introduction of particular measures. (Plate 3, Figs. 2, 3.)

The method designated the Chinese is the simplest that is practised, as all the boring tools are attached direct to the rope worked vertically up and down, the torsion of the rope giving sufficient rotary motion to the tool to enable it to strike a fresh spot at every descent. The facility with which the tools can be raised by the rope in this system seems at first to commend itself; but in practice, when sinking deep wells, it is open to serious objections, as, owing to the flexibility of the rope, the tool cannot be properly guided, and the bore-hole is likely to become crooked, which would in time interfere with the working of the tool; and in cases where the bore is to be lined with pipes, would render difficult, if not prevent, their insertion.

The ordinary plan adopted in boring is to attach the tools to a rod, consisting of a number of lengths jointed together; a vertical and circular motion is given to the rods. In deep wells much time is necessarily lost in raising and lowering a long length of rod, either to change the tool or bring up the débris. Various attempts have been made to economise the time thus spent; as, for example, it has been proposed to make the tools slide upon the square boring rods, and by attaching them by chains or ropes to a windlass, when they require raising, it could be speedily done, as in the Chinese system; because it would not be necessary to unjoint the rods, as required when using the ordinary tool. Another method, patented by Beart in 1844, was to make the rod of the boring tube hollow, and into this tube to introduce water, which, ascending outside the boring tool, was to produce a sufficient current to carry the materials, loosed by the boring tool, to the surface. A very great objection to this method (even supposing it to be practicable) is the necessity of having a large volume of water, which generally in boring cannot be easily procured until the spring is tapped.

In boring deep wells the weight of the rod and the force of the momentum in falling are very likely to break the tools used,

Digitized by Google

or the rods themselves, when special provision must be made to prevent it. This has been attempted in various ways. Thus, wooden rods hooped with iron have been substituted for the iron bar—tubular iron rods have been used, having the same weight per foot as the ordinary bar, but having a greater area; when working in water they lose a portion of their weight, equal to the volume of water they displace. Both wooden and tubular rods will answer very well when the depth is not great, but when the depth is great they are not sufficient to meet the exigencies of the case. When a sliding joint is used (Plate 3, Fig. 4)—this joint was introduced by Œuyenhausen, in Germany, M. Kind, in France, and in the system known as Kind's system in this country—any portion of the entire weight of the rods can be brought into action, as all those rods above the slide joint are counterbalanced by a weight suspended to a lever. In Kind's system the rods are often put in motion by a steam-engine, in the following way:—The rods are attached to one end of a lever resting on a fulcrum, the other end of the lever is attached to the piston-rod of an upright steam-engine; the valves of the cylinder are worked by a man; the rods are lifted by steam pressure and fall by their own weight.

The tools used in boring (Plate 3, Figs. 5 to 12, inclusive) differ according to the description of strata they are required to penetrate. Thus, when the strata is hard and compact, chisels of various descriptions are used to loosen the materials, which are either raised with an auger or shell pump, or miser. When the materials are of a soft nature, augers of various kinds are used.

It very often happens that in deep borings it is almost impossible to escape breaking the tools used; when special instruments have to be used to raise them. (Plate 3, Figs. 13, 14, 15.)

Towns Supplied from Wells.

The art of well-sinking in a great measure may be said to be empirical, and it by no means follows that because water is procured in some places from wells and borings in sufficient abundance to supply a town, that water can be procured anywhere by sinking or boring, as it requires a combination of circumstances not generally met with to render the work successful; and as all theory when applied under unknown circumstance may lead to error, a collection of examples of wells in use at various places where water is raised for public purposes will be highly useful in guiding us in estimating the quantities of water likely to be procured under given circumstances.

Birkenhead, Cheshire, is supplied with water from two wells,

Digitized by Google

395 ft. deep, partly sunk and partly bored in the new red sandstone formation. From experiments made upon one of these wells, when the water level was 120 ft. from the surface, the well yielded 1,807,461 gallons in twenty-four hours; by lowering the head another 4 ft., the well yielded 2,000,000 gallons in twenty-four hours.

Braintree, Essex, is supplied with 45,000 gallons of water per day, from a well sunk and bored in the chalk. The well is 9 ft. diameter, and 55 ft. deep, with a bore-hole at the bottom 340 ft. in depth, making the total depth of the well 395 ft. In this well the water level has been observed to rise with every rise of the tide, which is probably due to the hydrostatic head created by the tide impeding the free flow into the sea of some under current, which is consequently dammed back, owing to the increased resistance offered to its escape.

Brighton, Sussex, is supplied with 1,080,000 gallons of water daily from wells sunk into the chalk.

Bury St. Edmunds, Suffolk, is partly supplied from two wells sunk in the chalk to a depth of 86 ft., and connected by headings. There is about 130 ft. of heading, 6 ft. × 6.5 ft., in connexion with the two wells. Very accurate observations have been made upon the level of the water in these wells by Mr. John Croft, in the year 1860, and continued to the present time, and are tabulated in Plate 4. Observations made by the same gentleman on a hundred private wells sunk into the superficial strata of the town show that the water level in all is very nearly the same, and varies in any case but a few inches. The wells upon which these observations have been made were sunk by the local authorities, not with a view of supplying the inhabitants with water, but for the purpose of procuring a supply of water for watering the roads, and other public purposes; but since the original construction of the wells a portion of the town has been supplied. The quantity of water yielded by these wells fluctuates greatly, and is dependent upon the season of the year. Thus upon one occasion, after a trial continued over seventy consecutive hours, the well yielded water at the rate of 150,000 gallons every twenty-four hours; but the ordinary quantity supplied is about 60,000 gallons per day.

Coventry, Warwickshire, is supplied with 750,000 gallons of water per day from two bore-holes made in the bottom of the reservoir, 100 ft. diameter; the bore-holes are respectively 6 in. and 8 in. diameter, and 200 ft. and 300 ft. deep. The supply is procured from the red sandstone; and, from observations made, it has been found that the two yield water at the rate of 700 gallons per minute.

Croydon, Surrey, is supplied from two wells sunk into the

Digitized by Google

upper chalk, one being 75 ft., and the other 150 ft. deep. The latter well was sunk by Mr. Thomas Docwra, under the author's direction; and although sunk but 56 ft. from the old well, it has been proved, by careful experiments, that there is very little communication between the main body of the water in the two wells. Thus, when water at the rate of 1,000,000 gallons per day was being raised from each well, the relative water level in the two wells was not the same, but was 7 ft. lower in the new well than in the old. By stopping the pumping operations in the new well, and continuing them in the old, the water level in the new well rose 5 ft. above the water level in the old well, proving the two wells to be independent of each other. The quantity of water yielded by the old well during the last dry summer was at the rate of 1,500,000 gallons per day, and was only limited to this quantity on account of an insufficiency of steam power to raise more.

Dorchester is supplied with 180,000 gallons of water per day, from a well 120 ft. deep sunk into the upper chalk; the well is furnished with four headings, having a total storing capacity of 70,000 gallons.

Eastbourne, Sussex, is supplied with 200,000 gallons of water per day, from two wells partly sunk and partly bored 125 ft. into the upper greensand; the wells are provided with a heading capable of containing 10,000 gallons; the bore-holes are 7 in. diameter, and 60 ft. deep.

Enfield, Middlesex, is supplied with 90,000 gallons of water per day, from a well sunk and bored 215 ft. into the lower chalk; the bore-hole is 12 in. diameter, and 201 ft. deep.

Fareham, Hampshire, is supplied with 200,000 gallons of water per day, from two wells 12 ft. and 9 ft. diameter respectively, which have an adit or heading in connexion therewith capable of containing 30,000 gallons.

Kingston-on-Hull, East Yorkshire, was formerly supplied with river water, but during the present year (1864) the town has been supplied with water raised from a well sunk at Springhead, and forced by steam power to the old works at Stone Ferry, a distance of nearly five miles, from which place it is again pumped and distributed to the town. The well is sunk and bored in the chalk to a depth of 281 ft. 6 in., of which 210 ft. is an 18 in. bore. The well itself is 14 ft. diameter, and steined partly with iron cylinders and partly with brickwork. At the present time the well is yielding 3,500,000 gallons for the supply of the town; the water available is estimated by Mr. Thomas Dale, the engineer for the works, as not less than 4,000,000 gallons in twenty-four hours. Owing to the large influx of water, and the position of the pumps, special measures have been taken by the engineer to

Digitized by Google

shut out the water from the well when an examination of the pump valves is necessary. This is effected by lowering a conical weight weighing five tons into the bore pipe, the bottom of the well being covered with cast metal plates secured to the sides of the well and to the bore pipe. With this plug in the bore pipe it is found that one pump will keep down the water while any repairs are required to be made to the other pump. In sinking this well it was observed that the water was obtained from the under side of the layers of flint intersecting the chalk.

Liverpool, Lancashire, is partly supplied with water from wells sunk in the new red sandstone formation. Some of these wells yield as much as 3,250,000 gallons daily.

Margate, Kent, is supplied with 200,000 gallons of water daily, from a well 13 ft. diameter, and 50 ft. deep, sunk into the chalk; the well has a heading 400 ft. long, 9 ft. high, and 4.5 ft. wide.

Northampton is supplied with 518,400 gallons of water per day, from a well partly sunk and partly bored 250 ft. deep into the lias formation. (Fig. 37.)

Nottingham, is supplied with 2 million gallons of water per day from wells sunk into the new red sandstone.

St. Helen's New Waterworks derive their supply of water from two wells sunk in the red sandstone. Each well is 210 ft. deep, exclusive of the bore, and they furnish a supply of 572,000 gallons of water daily.

Salisbury, Wilts, is supplied with 600,000 gallons of water per day, from a well sunk in the chalk. The well is 8 ft. diameter, 50 ft. deep, and furnished with a heading 70 ft. long, 6 ft. high, and 2.5 ft. wide.

Selby, West Yorkshire, is supplied with 120,000 gallons of water daily, from a well partly sunk and partly bored to a depth of 330 ft. into the new red sandstone formation; the bore-hole of this well is 320 ft. deep, and 7 in. diameter.

Sheerness, Kent, is supplied from a well partly sunk and partly bored 380 ft. deep; it derives its supply of water from the upper greensand formation, and at the restoring of the well it yielded water at the rate of 220,000 gallons every twenty-four hours; the bore-hole of this well is 14 in. diameter, and 80 ft. deep.

Stourbridge, Worcestershire, is supplied with 150,000 gallons of water daily from a well 6 ft. diameter and 30 ft. deep, sunk in the red sandstone formation.

Tranmere, Cheshire, is supplied with 150,000 gallons of water daily, from a well 9 ft. in diameter, and 120 ft. deep, sunk in the new red sandstone.

Trevethin Waterworks Co., Pontypool, furnish a supply of 150,000 gallons of water daily, from springs flowing from the limestone rock.

Digitized by Google

Uxbridge, Middlesex, is supplied with water from two wells, each being capable of yielding 100,000 gallons per day.

Wallasey, Cheshire, is supplied with 300,000 gallons of water per day, from a well sunk and bored 236 ft. into the new red sandstone formation.

Wolverhampton, Staffordshire, is occasionally supplied with water from three wells sunk in the new red sandstone formation, which yield 500,000 gallons of water per day.

Designs of Wells.

In considering the best mode of constructing a well, many important matters have to be thought of, and some unforeseen circumstances may often cause the original plan to be set aside. Under this head it is proposed to give a brief outline of the construction of a few wells, which may serve as a guide in any similar work.

Amwell Hill Well, New River Water.—(Plate 5, Fig. 1.)—This well furnishes a supply of water equal to 2,460,000 gallons of water per day; it is entirely sunk in the chalk; for 84 ft. from the surface it is steined with 9 in. brickwork, then follows a sinking 10 ft. diameter without steining, but furnished with headings 6 ft. high and 4 ft. 6 in. wide. In the centre of this shaft a 2 ft. bore is made, which is succeeded by one 9 in. diameter. The entire depth of the well is 161 ft.

Birkenhead.—(Plate 5, Fig. 2.)—It has been already mentioned that Birkenhead is supplied with water from two wells; for all practical purposes, a description of the first well sunk will suffice. This well is entirely executed in red sandstone rock, and without steining. The total depth is 395 ft.; the first 95 ft. is 9 ft. diameter, then follows a bore of 26 in. diameter and 44 ft. deep; this is succeeded by a bore 18 in. diameter and 16 ft. deep, which is diminished to a bore of 12 in. diameter for an additional depth of 130 ft., and finally this is succeeded by a bore 7 in. diameter and 110 ft. deep. The water rises, after the cessation of pumping, to within 93 ft. of the top of the well; and, when reduced to a level of 134 ft. from the surface, the well yields 2,000,000 gallons of water every twenty-four hours.

Cheshunt Well, New River Company.—(Plate 5, Fig. 3.)—This well yields 702,000 gallons of water per day, and in its execution the following strata were pierced:—1 ft. 6 in. superficial earth, 8 ft. gravel, 45 ft. blue clay, 2 ft. yellow clay, 12 ft. white sand, 39 ft. dark coloured sand, then follows the chalk. The well is 171 ft. deep, and is steined partly with brickwork and partly with iron cylinders. For 12 ft. in depth the well is 11 ft. 6 in. diameter,

Digitized by Google

and steined with 14 in. brickwork; for a further depth of 44 ft. it is 9 ft. diameter and steined with 9 in. brickwork; of the 44 ft., 41 ft. is lined with cast-iron cylinders, 8 ft. diameter, which are also carried to a depth of 105 ft. from the surface. There are fifteen cylinders of this size in use, and they are succeeded by others 6 ft. 10 in. diameter, of which there are six in use; these are again succeeded by two cylinders, 6 ft. diameter. The whole of the cylinders are 6 ft. in depth. The bottom of the last cylinder is 118 ft. from the surface, at which point they rest upon a foundation of 9 in. brick steining, 7 ft. in depth. At the bottom of the 6 ft. cylinders the well widens out in the form of a cone 12 ft. 6 in. diameter at the floor, which is 26 ft. below the bottom of the 6 ft. cylinders. In the centre of the well a bore-hole 3 in. diameter and 27 ft. deep was made, and the well is provided on the floor level with headings 7 ft. high and 4 ft. 6 in. high.

Cheshunt—Well of Sir Henry Meux.—(Plate 5, Fig. 4.)—This well is 202 ft. 6 in. deep, and derives its supply of water from the chalk. It is an ordinary well, steined with brickwork. The surface water is prevented from entering the well by making the well concentric at the top, the space between outer and inner wells being afterwards filled in with puddle. The well itself is 71 ft. deep, steined with 4½ in. brickwork. It is executed for the remainder of the depth by bore-holes, varying in diameter from 7 in. to 4 in. In executing it the following strata were pierced:—5 ft. gravel, 59 ft. blue clay, 12 ft. coloured clay, 1 ft. dark coloured sand, 5 ft. 6 in. sand and pebbles, 3 ft. bright sand, 35 ft. dark sand, 1 ft. flints, 2 ft. chalk flints, 1 ft. flints, the remaining distance of 78 ft. being entirely chalk.

Guy's Hospital.—(Plate 5, Fig. 5.)—The well is sunk through the London clay into the chalk, and the following is a description of the strata pierced:—8 ft. superficial earth, 2 ft. yellow clay, 1 ft. black loam, 3 ft. peat, 19 ft. gravel, 63 ft. blue clay, 22 ft. mottled clay, 4 ft. dark blue clay, 5 ft. shells and sand, 10 ft. mottled clay, 4 ft. sand and pebble, 4 ft. mottled clay, green coloured sand and pebbles, 4 ft. green coloured sand and pebbles, 3 ft. green coloured sand, 44 ft. grey sand, succeeded by a layer of flints, and then the chalk. The total depth of the well is 298 ft. 6 in. For 9 ft. in depth it is 8 ft. diameter, and steined with 9 in. brickwork; which is succeeded by five cast-iron cylinders, 4 ft. 6 in. diameter, each cylinder being 5 ft. deep. Below these cylinders, and for a further distance of 96 ft., the well is 4 ft. 6 in. diameter, and steined with 4½ in. brickwork, then follows 2 ft. of 9 in. steining, the whole resting on the bottom of the well, which is executed in 18 in. brickwork. In the centre of the well a bore-hole is made, which is lined with a 12 in. iron

Digitized by Google

pipe, the pipe being continued 72 ft. 6 in. above the bottom of the well, and within 60 ft. of the surface.

Kensington Gardens.—(Plate 5, Fig. 6.)—This is a well that was sunk for supplying the Serpentine. It is 321 ft. in depth, and the water rises within 105 ft. of the surface. The following is a description of the strata pierced in making this well:—2 ft. of surface earth, 170 ft. blue clay, 2 ft. petrified wood, 7 ft. dark coloured sand, 43 ft. 6 in. coloured clays, 1 ft. 6 in. sand, 4 ft. pebbles, 30 ft. sand, 3 ft. 3 in. flints, 54 ft. 5 in. chalk, 3 ft. 3 in. flints. The well is 6 ft. diameter for 203 ft. deep, and steined with brickwork as follows:—For the first 25 ft. with 9 in., 67 ft. 6 in. with 4½ in., 5 ft. with 9 in., 10 ft. with 14 in., 5 ft. with 9 in., 91 ft. with 4½ in. The remaining portion of the well is lined with 4 ft. 6 in. iron cylinders; there are twenty-three of these cylinders in use in the well, and they are continued up the well within the brick steining, a distance of 60 ft. The bottom of the well is filled up with concrete, through which a boring is made and lined with a 12 in. pipe, 18 ft. in length; the top of the pipe is about 5 ft. above the bottom of the well; the remaining portion of the boring is lined with an 8 in. pipe.

Northampton Waterworks.—(Plate 5, Fig. 7.)—This well is sunk in the lias formation, and pierces the following strata:—3 ft. made ground, 13 ft. 9 in. rubble stone, 6 ft. stone, 135 ft. 3 in. blue cluncle, 14 ft. 3 in. hard stone, 18 ft. 6 in. clay stone, 9 in. stone, 35 ft. 6 in. clay stone, 3 ft. stone, 23 ft. 3 in. clay stone. The well is steined with brickwork and iron cylinders in the following order:—For 16 ft. 9 in. in depth the well is 7 ft. 6 in. diameter lined with brickwork; at this depth two cast-iron cylinders, 5 ft. 6 in. diameter, are introduced, which are again succeeded by 9 in. brick steining, commencing at 5 ft. 6 in. internal diameter, and widening out to 7 ft. 6 in. diameter; the floor of the well formed in brickwork at 120 ft. in depth from the surface; in this floor the boring commences, and for the first 31 ft. it is lined with 14 in. pipes, which rise into the well 5 ft. above the floor. The remaining portion of the bore-hole, 89 ft., is 9 in. diameter.

Southampton.—(Plate 6.)—The well sunk on Southampton Common, with the intention of supplying water to the town, turned out to be a failure as regards procuring a supply of water, although it is a fine example of the art and skill of the well sinker. The well is sunk to the depth of 563 ft., and bored a further distance of 754 ft., making a total depth of 1317 ft. The upper portion of this well was executed in brickwork. At 10 ft. from the surface iron cylinders, 13 ft. diameter, were introduced, which were continued to the depth of 62 ft. from the surface, when the contractor failed in his work, which at this depth was 2 ft. out of the perpendicular. The work was now

Digitized by Google

undertaken by Mr. Thomas Docwra, a gentleman who has had great experience in well sinking; but, before the fresh work could be proceeded with, it was necessary to secure and strengthen the upper cylinders, which, owing to the violent measures used to drive them, were cracked and broken in all directions. This strengthening was accomplished by the introduction of cast-iron curbs, suspended from the flanges of the cylinders; and when the work had been in this manner thoroughly secured, the new work was proceeded with; three built up cylinders 8 ft. 6 in. diameter were introduced within the 13 ft. cylinders, and extending about 3 ft. below them; then steining with brickwork was commenced, which gradually widened out until at the depth of 72 ft. it was 14 ft. diameter; steining was continued to the depth of 164 ft., and was lined within with iron cylinders, backed with concrete; at this depth (164 ft.) a set-off was made and the well was continued in 14 in. brick steining, having a diameter of 11 ft. 6 in., until the well had reached the depth of 214 ft., when another set-off was made and the well was continued in 14 in. brickwork, 10 ft. diameter, to the depth of 267 ft. from the surface; at this depth another set-off was made, and the well was continued in 9 in. brickwork, 8 ft. 6 in. diameter, until the well had reached the depth of 302 ft.; when at about this depth it was ascertained that the work would have to be continued through a bed of running sand, and special means were adopted to secure the work above. These means consisted of the introduction of an iron curb, and the work was suspended by iron rods to another curb at the set-off, 267 ft. from the surface; this latter curb, in its turn, was suspended by means of strong chains to the bottom of the cast-iron cylinders at 163 ft. from the surface. When the work had been thus secured, a single cylinder of cast-iron 8 ft. diameter, extending 2 ft. within the 9 in. brick steining, was introduced, and below this 4½ in. brick steining, lined with cast-iron cylinders 7 ft. diameter, was executed, the space between the brickwork and the cylinders being filled with puddle. A sluice was made in one of the cylinders, which could be opened to admit water at pleasure; at 322 ft. from the surface the use of iron cylinders was discontinued, and the work was carried forward in 9 in. steining, the well being 6 ft. 9 in. diameter, to the depth of 467 ft., at which point the steining was terminated upon 18 in. footings of brickwork bedded in the chalk. The remaining portion of sinking was executed in the chalk, without the use of steining, until, at the depth of 563 ft., a trial bore 7 in. diameter was made to an additional depth of 754 ft., when owing to the great expenses incurred, and the probability that if water was to be reached at all it would be salt and unfit for the purposes required, this enterprise was abandoned.

Digitized by Google

Southend Waterworks.—(Plate 5, Fig. 8.)—This well is an ordinary steined well 416 ft. deep; for 201 ft. deep it is 6 ft. diameter, and steined with 9 in. brickwork, the remaining 215 ft. is 4 ft. 6 in. diameter, and steined with 4½ in. brickwork. The well is sunk through the following strata:—3 ft. surface soil, 30 ft. yellow clay, 383 ft. of blue clay; at this depth a bed of running mud was encountered, and the water rose to within 100 ft. of the surface.

Wormley, Herts.—(Plate 5, Fig. 9.)—This well is 135 ft. 6 in. deep, and is sunk in the chalk. The water rises to within 61 ft. 8 in. of the surface. For 38 ft. the well is 4 ft. diameter, at which point it commences to widen, until at 50 ft. it is 6 ft. diameter, at which size it is continued until 70 ft. is reached; the whole of the work is steined with 4½ in. brickwork; for 15 ft. deeper the well is 3 ft. 9 in. diameter, the upper portion of which is steined with wooden curbs, the well terminates in a bore 6 in. diameter, and 50 ft. 6 in. deep. In executing this well the following strata were pierced:—1 ft. surface earth, 9 ft. loam, 10 ft. yellow clay, 12 ft. blue clay, 6 ft. brown sand, 14 ft. white sand with pebbles, 20 ft. brown sand with water, which was succeeded by the chalk.

Absorbing Wells.

Wells and borings have been occasionally made for absorbing waste water, which is conveyed into the absorbent strata, and which, being disseminated over a large district, finally makes its escape at the points of natural overflow. It has been observed that, in making use of wells for this work, any ordinary well will absorb a quantity of water equal to its yield, provided that the water is free from matter likely to choke the pores of the absorbent strata. Thus it has been proved that if the natural water level in a well is 20 ft. from the surface, and by reducing the water level to 30 ft. from the surface, the well will yield 100 gallons per minute; by raising the water level 10 ft. from the original level, or within 10 ft. of the surface of the ground, the well will absorb water at the rate of 100 gallons per minute. Wells of this description have been executed in many places purposely to get rid of surplus water; thus an extensive plain near Marseilles, which was originally a morass, had been effectually drained in this way. In this country it has often been found that, to carry out agricultural drainage, water may sometimes be got rid of by simply boring through the upper crust of clay or other impervious strata into the porous strata below. Absorbing wells should not, under any circumstances, be used except to take away pure water; as the effect of discharging impure water into these wells would be to contaminate the wells

Digitized by Google

December 19*th*, 1864.

W. T. CARRINGTON IN THE CHAIR.

ON WATER SUPPLY.

By BALDWIN LATHAM.

ADJOURNED DISCUSSION.

MR. GLYNN opened the discussion by observing that the author of the paper had not drawn the attention of the meeting to any particular kind of rain gauge, and he had only considered the subject of the construction and placing of those gauges of such vital importance to engineers, because all their data as to the probable amount of water to be collected from any given area, whether as surface drainage, or underground drainage, must be dependent, in the first instance, on the amount of rainfall in the district; and that could only be ascertained by means of correct and properly placed gauges. That being the case, he would lay before the meeting the results of some failures, both in the construction and the placing of rain gauges.

Before, however, giving those results, he would explain the diagrams which he had prepared. No. 1 represented the form used by the Literary and Philosophical Society of Manchester, and of which a number were fixed in the neighbourhood of that city. That gauge consisted of a hollow cylinder of copper, or other metal, about 7 or 8 inches in diameter, and from 36 to 40 inches in length, with a receiving funnel of the same diameter as the cylinder, and closely fitted to the top. Within the cylinder, a float rose as it became filled with water. It was just so much smaller in diameter as to rise freely, and in the centre was fixed an upright rod ($\frac{1}{2}$ in. diameter) marked in inches and tenths of an inch, which, rising through a small hole at the bottom of the funnel, exactly indicated the depth of rain falling in any given time. The surface of the water in the cylinder being completely covered with the float, except the mere annular space of about $\frac{1}{8}$ in., no evaporation took place. The gauge must be occasionally emptied of the water it contained. It was sunk in the ground, within a strong box, or case, to

Digitized by Google

Fig.

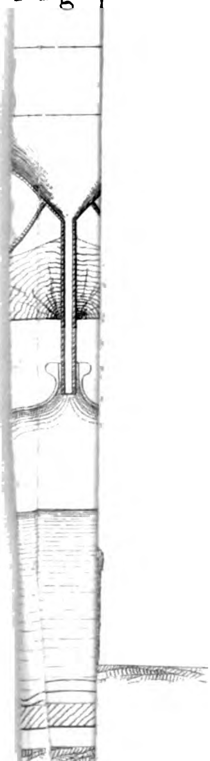
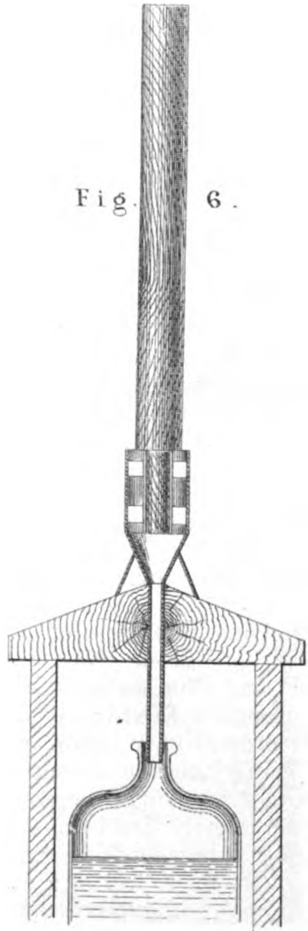


Fig. 6.



Digitized by Google

Digitized by Google

prevent injury, and to allow of its being easily taken out; the top of the gauge being left about 10 or 12 inches above the ground.

No. 2 was the gauge used by the Manchester, Sheffield, and Lincolnshire Railway Company, on the Peak Forest and Macclesfield Canals. That gauge was made of copper, and, as would be seen by the drawing, had the upper part made cylindrical, the lower portion being in the form of a funnel, with a tube passing into a bottle, enclosed within a wooden box, to preserve it from injury. The diameter of the cylindrical portion was 9 in, the tube being $\frac{3}{8}$ in. in diameter. The rain falling upon the gauge, passed into the bottle underneath, and the water was then emptied out into a cylindrical vessel, with a glass gauge attached, which measured accurately the water that had fallen in the bottle. The opening in the bottle being so small, little or no evaporation of the water could take place.

No. 3 was partly of the same construction as No. 2, but instead of the upper portion being cylindrical it was made conical, the assumed object being to prevent the rain, when drifting, from splashing out of the gauge.

No. 4 was the form of gauge recommended by Mr. James Glaisher, F.R.S., Secretary to the Meteorological Society of London. The cylindrical portion was 8 in. diameter and 13 in. high; it was sunk into the ground 8 in., the top edge being 5 in. above the ground. Into the top or mouth of the vessel was fitted a funnel 6 in. deep, the bottom of the funnel ending in a bent tube of $\frac{1}{8}$ in. in diameter, bent so as to form a trap and prevent evaporation, but yet discharging the water freely into the vessel below.

No. 5 was made as an experimental gauge by the late Mr. J. Wood, engineer to the Peak Forest and Macclesfield Canals; it consisted of a staff $\frac{1}{2}$ in. in diameter, standing 12 in. in height above the cover of a cylinder 7 in. in diameter, having a hole 1 in. in diameter through the cover.

No. 6 was also an experimental gauge, and consisted of a staff of wood $18\frac{3}{4}$ in. long, and 2 in. in diameter, fixed in a small metal cylinder, at the bottom $2\frac{1}{2}$ in. in diameter. The exposed surface of the staff, equal to half the circumference by 18.75 in. + area of circle $2\frac{1}{2}$ in. in diameter, exactly equalled the area of a circle 9 in. in diameter, or 63.61 square inches. The rain falling on and against the staff passed down through the metal cylinder into a bottle, so that the amount could be measured.

There was also another rain gauge called "Osler's Anemometer," which not only recorded the rainfall, but the direction and force of the wind at the same time. It was, however, a

Digitized by Google

complicated piece of mechanism; and he (Mr. Glynn) only mentioned it as one of the gauges then in use.

Having described the gauges, he next traced their action more closely. In Nos. 1, 2, 3, and 4, the construction generally was somewhat similar; that was, the water collected on the surface of the cone was carried into a receptacle underneath; there the similarity ended, for in No. 1 there was a means of measuring the amount of rainfall without emptying the water so collected into any other vessel; whereas the other gauges required that process. But No. 1 had a serious defect, by showing the rainfall in excess, the more especially when placed in high and exposed positions. Nos. 5 and 6 were constructed for the express purpose of proving the inaccuracy of No. 1, and those experiments he (Mr. Glynn) would now lay before the meeting.

In 1844 the late Mr. John Wood placed a No. 5 gauge near the ground at Marple, near Manchester, and it collected in six months, from the beginning of July to the end of December, 9.5 in. in depth of water, in the 7 in. cylinder. The result was obtained from the rain beating against and running down the stick, and falling through the hole in the top. From the beginning of January to the end of December, 1845, the same gauge collected 21.95 in. in depth; in 1846, 15.4 in. in depth; and in 1847, 22.48 in. in depth. That experiment fully proved that if the stick communicating with the float of gauge No. 1 rose above the top of the gauge, considerable error was introduced in the results shown by gauges of that construction. Having discovered that so great an amount of rain was collected, No. 6 gauge was constructed and placed near No. 2 gauge in four different positions, and, as before described, the staff gauge was of equal area to No. 2 gauge; so that a comparison could be made between the collecting power of the two gauges. The mean results for 1847 were as follows:—

Locality.	No. 2 Funnel.	No. 6 Staff.
	Inches.	Inches.
Todd's Brook, brinks top of hill, 1500 ft. above level of sea......	29.50	46.87
Do. do. reservoir bottom of hill, 620 ft. do. do.......	38.39	20.67
Coomb's Ridge, top of hill, 1670 ft. do. do.......	35.05	58.99
Do. reservoir, bottom of hill, 720 ft. do. do.......	51.30	27.89

Those results showed that the more exposed the gauge, the greater the error became, where the gauges had staffs. He (Mr.

Digitized by Google

Glynn) thought that the form of the gauge was a most important consideration. The next would be the placing of the gauges, and on that point he would quote some failures as examples. Several gauges (No. 2) were placed on the ridging of the roofs of the lock-keepers' houses of the Ashton and Peak Forest Canals, under the impression that, from the exposed position, all the rain which fell would be caught; but on placing other gauges on the ground, a difference of from 41.92 to 58.76 per cent. more rain was recorded; and although there could not be a doubt that some of this difference was owing to the kind of gauge used, viz., No. 1 gauge; still there might have been some of the rain carried over the funnel gauges by the currents of wind created by the sloping roofs. From those facts, the only conclusion that could be arrived at was that the more free and naturally (if he might use the expression) a gauge was placed, the more probability there was of arriving at the true rainfall.

As it might be supposed that evaporation would take place with the No. 2 gauge, an experiment was made by Mr. S. C. Homersham, C.E., in May, June, and July, 1848, by placing bottles of 2½ in. diameter, with an open neck of ¾ in. in diameter, in each of the rain gauge stands; the level of the water put into the bottles being marked on the outside; the result was, that Mr. Homersham could not observe any difference in the level of the water; so that the amount of evaporation might be taken as inappreciable.

With respect to infiltration and evaporation, he (Mr. Glynn) would observe that as Mr. Latham had quoted some results of experiments made at Apsley Mill, he considered it would be advisable to examine the instrument used, as the question of percolation was of equal importance with the proper record of the rainfall. He would read the description of Dr. Dalton's gauge, as described in Rees's Cyclopædia:—"They took a cylindrical vessel of turned iron, 10 in. in diameter, and 3 ft. deep; there were two pipes soldered in it, one at the bottom, the other at the top, for water to run into the bottles. The vessel was filled with gravel, sand, and soil, and subsequently the soil was covered with grass and other living vegetables. It was nearly buried in the ground in an open situation, and provision made for placing bottles to the two pipes; in this manner it was exposed to receive the rain, and to suffer evaporation from the surface, the same as the surrounding green ground. A regular register was kept of the water which percolated through the soil and gravel into the bottles, and a rain gauge, of the same surface, was kept close by, for the sake of comparison."

The Apsley Mill instrument was supposed to be a copy of

Digitized by Google

this; but when the gauge was first used, and indeed up to 1852, the case of the gauge was made of wood, the top part of it had shrunk so much that a shilling could be passed through the joints; and there was good reason to believe that the portion in the ground was equally faulty. Besides which the overflow pipe was not connected with any bottle to measure the amount of water running off the surface. Since that date (1852) there was no doubt the gauge had been altered. Be that as it might, the test of the accuracy of those experiments would be found by examining the results of the infiltration, as given in Mr. Beardmore's valuable papers, from which he had constructed the following table of the mean results.

	Inches.	Mean of rainfall same time.
The mean result of infiltration for 5 years, from 1835 to 1839 was	11.20	26.82
Do. 1840 to 1844 „ „	10.6	26.00
„ 1845 to 1849 „ „	6.88	25.72
„ 1850 to 1854 „ „	5.86	26.11
„ 1855 to 1859 „ „	5.62	26.75

By the table it would be seen that in the first five years the comparative infiltration to the rainfall was 41 per cent.; and in the last five years only 21 per cent.; the difference increasing each successive five years. The question was, how had that occurred? because on examining the amount of rainfall, the difference did not exist there. Then the natural assumption must be either that the gauge itself was faulty, or the records could not have been accurately kept. Mr. Beardmore thus remarked upon the discrepancy in the records:—"In the Apsley Mill series there appears to be a tendency in the gauge to show less filtration on each average of five years. It is probable that this may partly arise from the general fact of the gradual *puddling* and consolidation of the materials of the gauge in so limited an area; and there is some indication of the materials filling the gauge having possibly been changed after the year 1844." He (Mr. Glynn) thought he had shown that these observations could not be relied upon, much as such a series was required. It would be necessary for engineers to look to other sources for the probable amount of infiltration; and he could not do better than refer to the following tables, which had been got up with great care by Mr. S. C. Homersham, for the pur-

Digitized by Google

pose of showing by practice the amount of drainage running off from different formations. They were originally published in the Journal of the Society of Arts.

Table giving the area in square miles of the different Geological formations in the south-eastern portion of England, the length of river courses in miles upon each separate formation, and the length of stream, or river course, per square mile.

Geological Formation.	Area	Absolute length of streams or river courses.	Comparative length of stream, &c., per sq. mile.
	Square miles.	Miles,	Yards.
Crag	2056	1996	1709
Bagshot sand	168	165	1729
London and plastic clay	4071	4741	2057
Chalk and upper green sand	5353	2391	782
Wealden clay	763	905	2087
Hastings sand	577	700	2135

Table showing the area of the water-way of nine pairs of bridges. One bridge of each pair has a drainage-ground of the chalk formation, and the other, as nearly as could be found, a similar area of drainage-ground of the London clay formation.

Digitized by Google

Situation of Bridges.	Area of water-shed, or drainage ground.	Geological formation.	Area of water-way.	Observations.
	Sq. miles		Sq. feet	
Mountneysing, Essex, River Roding	11½	London clay	191	Often filled with water.
Kimpton Hoo Park, Herts., River Misuram	12¾	Chalk	19	Never full of water.
Chipping Ongar, Essex, River Roding	21	London clay	279	Often filled with flood water.
Welwyn, Herts, River Misuram	23½	Chalk	26½	Never full of water.
Colney Street, Herts, River Colne	39½	London clay 28¼; Chalk 10¾	267½	Often filled with water.
Saint Alban's, Herts, River Ver	38	Chalk	48½	Never two-thirds filled with water.
Near Margaretting, Essex, River Chelmer	42½	London clay	350	Bed of river and piers show signs of heavy floods.
Park Street, Herts, River Ver	43	Chalk	65	Rarely half-filled with water, even after heavy falls of snow.
Writtle, Essex, River Chelmer	49	London clay	358	Frequently filled with water after floods.
Chalfont, St. Peter's, Bucks., River Misbourne	49½	Chalk	40	Never half-filled with water.
Coggleshall, Essex, River Blackwater	58	London clay 48; Chalk 10	179½	Often filled with flood water.
Denham, Bucks., River Misbourne	56	Chalk	19	Never filled
Helvedon, Essex, River Blackwater	62	London clay 52; Chalk 10	390	Often filled with flood water.
Stanborough, Herts., River Lea	61	Chalk	50	Never three-fourths filled with water.
Stappleford Abbots, Essex, River Roding	79½	London clay 73½; Chalk 6	495	The water-way not sufficiently large to carry off ordinary floods. The country above is often flooded for miles.
Hertford, Herts., River Bean	72	Chalk partially covered with impermeable drift	173	Rarely half-filled with water.
Loughton, Essex, River Roding	99½	London clay	693	Often filled with flood water.
Winchester, Hants, River Hitchin	102	Chalk	187	Never two-thirds filled with water.

Digitized by Google

It would be seen that on the chalk formation, comparatively little rainfall could be taken as effective for storage puposes in reservoirs when taken from the surface only. In 1860, he (Mr. Glynn) read a paper before the society, from which he would now quote, to show the great absorbing power of the chalk: "On the Chilton ridge, on the North of London, there are more than 200 square miles of country without a stream, river, or surface spring to be seen upon it. In Kent, between Lewisham and Stroud, 26 miles, there is only one stream which has its source in the chalk district (viz., the Cray), which runs off that area. The River Darent, having its source in the Weald, does not obtain any of its volume from the chalk; but, on the contrary, there is good reason to believe the flood-waters of the Weald are absorbed by the chalk in their passage to the sea. And from Stroud to the coast, some 40 miles, there is only the River Stour besides the Medway. The Medway takes its rise in the Weald, and is almost wholly fed from that source. The Stour also rises on the borders of the Weald and Lower Greensand; therefore, taking round numbers, the area is about 600 square miles, with these last two rivers upon it. On both the North and South Downs there are numerous valleys, but even after the thawing of the snows of last year (1859), the author failed to trace so much as a temporary water-course, although the hills on the escarpment side are very steep. Indeed, it is proverbial with the farmers in the chalk districts, that they can plough their land half an hour after the heaviest rain. The areas of the bridges on the streams running off the chalk are only from $\frac{1}{5}$th to $\frac{1}{10}$th the area of those on the clay." With those remarks, he would leave the question of infiltration and proceed to the consideration of evaporation.

It did not seem to him (Mr. Glynn) that after all the experiments made (and there were many), that engineers were in a much better position to estimate the probable amount of rainfall lost by evaporation; or that any reliable data could be deduced by which to govern the amount of rainfall available for storage. In fact, the only use he could see in those experiments, as far as the engineer was concerned, was to estimate the amount lost by evaporation from the water in the reservoirs. That that was the case, he would endeavour to prove by means of the following table, which he had compiled from Beardmore's Hydraulic Tables.

Digitized by Google

Situation of Gauges and name of Observer and time of Observation.	Rainfall.	Evaporation.	Per centage of rainfall evaporated.
	Inches.	Inches.	
Mr. Luke Howard, Plaistow, for 3 years (1812 to 1815)	23.15	21.13	91
Mr. Charnock, Ferry Bridge, Yorkshire, for 5 years (1842 to 1846)	24.60	35.04	142
Bolton-le-Moors, Lancashire, for 10 years (1844 to 1853)	45.96	25.65	58
Whitehaven, Cumberland, for 10 years (1844 to 1853)	43.50	29.21	67
Little Bridy, Dorset, for 3 years (1858 to 1860)	41.44	25.91	62
Radcliffe Observatory, Oxford, for 5 years (1852 to 1856)	27.22	31.03	114
Mean result for England	34.31	27.98	89
Georgetown Observatory, Demerara, for 3 years (1854 to 1856)	90.08	35.12	39
Bombay, for 5 years (1849 to 1853)	78.60	82.28	105
Mr. Jackson, Ballarat, Geelong and Melbourne, Australia. Mean of the above places for 1 year, 1857	24.15	61.46	254
Vallês at Dijon, France, for 7 years (1846 to 1852)	26.90	26.10	97
Copenhagen District, Denmark, mean of 5 places, 12 years (1848 to 1859)	22.92	27.90	121
On short grass	...	30.10	131
On long grass	...	44.00	192

By that table it would be seen that taking a mean from six different observers, the observations taking place over periods of five years, the result obtained would be (the rainfall being 34.31 in.) 27.98 in. due to evaporation, or 89 per cent.; leaving only 11 per cent., or 6.33 in. of rainfall to supply the rivers, &c. This was taking the mean of the experiments in England; but if some of the individual experiments were taken, as at Ferry Bridge, in Yorkshire, it would be seen that the evaporation was actually recorded as 42 per cent. more than the rainfall. In Denmark the case seemed worse than in Yorkshire; the evaporation, as recorded, being 121 per cent. from the surface of water, and from long grass 192 per cent. of the rainfall.

Such being the facts of the case, it would be necessary, as in the case of infiltration, to obtain information from some other source; fortunately it was obtainable from the gaugings taken of many rivers and streams. From those results it would be found that the loss due both to infiltration and evaporation varied from 50 to 10 per cent. of the recorded rainfall, leaving as available

Digitized by Google

for storage purposes, irrespective of mill or river necessities, from 50 to 90 per cent. of the rainfall; he therefore thought that it was only from reliable results on the relation of discharge to the actual rainfall, that could give any safe guide as to the quantity of water a given area of drainage-ground would yield; not forgetting the importance of its geological character, and how covered; as those conditions would materially alter the quantity of water running off. The storage reservoir capacity would show how much water various engineers had considered available from off the different drainage areas; and taking one square acre, a comparison could be readily arrived at. The following table had been constructed for that purpose:

Remarks.	Cubic feet storage room for 1 square acre of drainage ground.	Situation, &c.
The whole fall not impounded	34,000	Manchester Waterworks
	43,430	Belmont Reservoir
	49,000	Rivington Pike
	49,100	Turton and Entwistle Reservoirs
	66,150	Gorbals Reservoir, Glasgow
	39,912	Loch Katrine
	19,767	„ Vennacher
	80,000	„ Dumkie
	87,000	River Bean Reservoirs

From that table, it would appear that the rainfall, available for storage, would vary from 18 in. to 36 or 40 in. per annum. But in hot climates the storage room would seem to be much greater; as, for example, Mr. Conybeare allowed 438,956 cubic feet per square acre of drainage ground at Bombay; while Mr. Bullock Jackson, at Melbourne, allowed 195,673 cubic feet per square acre. The storage room being so much out of proportion, one to the other, it was only by the rainfall that the reason could be found, as at Bombay it was 124 in., and at Melbourne 28.55 in. The author of the paper had exhibited numerous drawings of wells sunk by Mr. Docwra, but he had not mentioned the cost of them. Now he (Mr. Glynn) was of opinion that the cost was of as much importance as the quantity of water supplied by them.

Mr. Morris said he had had some experience in well sinking, and that Mr. Latham had omitted to describe the character of the chalk stratum. He (Mr. Morris) had found that where the chalk was solid and undisturbed, it was too compact to allow much water to find its way through it into a well; but where the

Digitized by Google

stratum was traversed by faults and upheavals, there the chalk was loose and broken, and water readily flowed through it. For instance, in sinking bore-holes, it often occurred that after boring slowly through the solid chalk, the tool would suddenly drop down several feet into a fissure filled with loose chalk, where large quantities of water were frequently met with. The fissures, which probably extended for a considerable distance, allowed the water which oozed slowly through the solid chalk to flow free through them. If they were tapped, the well would probably yield a good supply of water; but from the solid rock itself little water would be obtained. He thought that engineers should carefully examine the general character of the chalk formation in the locality before selecting a site for a well, and sink it as close as possible to the upper side of a fault. Natural springs often afforded indications of those disturbances.

The CHAIRMAN asked Mr. Morris if he could give the yield of the wells he had quoted, and also the cost of sinking them?

Mr. MORRIS stated that the last well sunk for the Kent Waterworks, at Deptford, yielded about 3,000,000 gallons a day. There were two others at the same station affording a supply of 1,500,000 gallons. The well at their Charlton station yielded about 1,250,000, and that at Plumstead about 800,000 gallons per diem; but those quantities could be increased if the pumping were continued throughout the twenty-four hours.

Mr. SIEBE said he believed that of late the supply of water from the London wells had been falling off, and that the cause was not exactly known. There was a well in the Home Park, which, when it first came under his care, had some 22 ft. above the cylinders, but which was now much less. In digging one well, the water rose so suddenly, that there was no time to put on a proper piece of suction, but the suction was afterwards lengthened, when the well went on for eight or ten months and then failed. The cylinders were lowered to the water surface, and it went on for another year; but a few days since the water lowered again. Originally there were over 200 ft. of water in the well, but there were then only about 130 ft. As regarded the deficiency of water in London, one reason assigned was that the surface of London was becoming so covered with houses as to prevent filtration. Another reason assigned was the system of agriculture adopted, by which the fields were drained instead of the water being allowed to filter. He did not think there was a well in London in which the water was not decreasing greatly. Most London brewers were obliged to use surface water. Although wells were sunk deeper, they did not yield a proportionate supply, which led to the conclusion that filtration was stopped in some way.

Digitized by Google

Mr. OLRICK said, as the question of the Hull pump had been raised, he would read the following extract from the official report, dated July 5th, 1863: "On the 10th of November, a flint, 12 in. in thickness, was penetrated at the depth of 235 ft. from the surface; the flow of water up the borehole increased at once to a yield of 3,000,000 gallons per twenty-four hours. . . . On the 7th of December, about 2 P.M., the boring chisel penetrated a horizontal fissure of 4 in. in depth, at the depth of 178 ft. below the bottom of the shaft, the Jackson engine pumping at the same time at the rate of 3,000,000 gallons per twenty-four hours. A rush of water was immediately perceived, which rose in the course of ten minutes from a depth of 10 to 20 ft. in the shaft, much discoloured with chalk. The water in the old bores, which had previously stood at a level of 4 ft. below the line of overflow, sunk to a depth of 8 ft. The Jackson engine was at once put to her full speed; the water in the old bores sunk during the night to a depth of 11 ft. 6 in. The day following, viz., Tuesday, the water in the old bores again rose 18 in., and although the Jackson engine pumped at the rate of 3,000,000 gallons per twenty-four hours, she was unable to lower the water in the shaft below the depth of 20 ft. At this time I estimated the yield of water available, at the least, to amount to 4,000,000 gallons per twenty-four hours. The bore hole is 18 in. in diameter, and has been carried down to a depth of 210 ft. below the bottom of the shaft. On the 29th of January, the Jackson and Fountain engines were started together, and since that time up to the present have worked satisfactorily (with the exception of stoppages for a short time, caused from the bottom valves having to be cleared of débris scoured out of the fissures lately penetrated), and furnished a continuous supply for the use of the inhabitants of the town. . . . . The engines together were specified to be capable of lifting 5,000,000 gallons of water in twenty-four hours, but they are capable of lifting together 6,000,000 gallons per twenty-four hours." He did not believe that a better answer could be given than a report from the resident engineer to the Hull Waterworks Committee, and as that report was authentic, he believed that question was fully answered. A remark had been made with respect to the quantity of rain being greater at the top of a mountain than lower down. He did not know whether any others had made the same mistake as was some time ago made in respect to steam pistons, namely, of making them semi-circular or saw-shaped, instead of straight, contending they were more efficient because there was more surface. As regarded staff gauges, he thought Mr. Glynn's remarks were perfectly correct, and supposing the rain were to fall vertically, the staff gauge could not register anything whatever. There was

Digitized by Google

one point in connexion with gauge No. 6, to which he might draw attention. Mr. Glynn said it was entirely closed up to prevent evaporation. That was quite correct in theory, but it would absolutely prevent any water getting into the bottles or reservoirs underneath. He then reverted to the remarks of the chairman of the Hull Board, which were to the effect that river water was taken into the mains not for drinking purposes but only in case of fire, and in the morning if there had been no fire, he believed it was allowed to run out again.

Mr. Glynn said that if Mr. Olrick would read the report again it would be found that the chairman said that there was an extra charge for cleaning out the basin, arising from the necessity of river water to a small extent having been introduced. Referring to gauges, Mr. Olrick had said there was more rain recorded on the top of the mountain than elsewhere. He (Mr. Glynn) had before remarked the same, which was accounted for by the fact, that any staff gauge placed in an exposed position would have rain beat against it.

Mr. Olrick asked whether it was not more likely that the more exposed the position of the gauge, the more the rain would be beaten off the staff.

Mr. Glynn said the proof was that it did not do so, as shown by the result of those gauges at the tops of mountains. He thought No. 2 gauge was the best. He believed that the Philosophical Society of Manchester had made a large number of experiments, and that they had still agreed to use Mr. Bateman's gauges. Mr. Siebe had stated that one reason assigned for the chalk not yielding a good supply of water, was the continuous house building and the London clay preventing the percolation of the water through it. From experiments made upon different specimens of chalk, it was found that the chalk under London was more dense than that referred to by Mr. Morris. One cubic foot of chalk taken from under the London clay when dry, weighed 142 lbs. 14¼ oz., and would take up only 0.897 of a gallon of water. The chalk at Gravesend was not so dense, one cubic foot when dry weighing 93 lbs. 10¾ oz., and would take up 2.542 gallons of water. That showed the pores of the chalk were different, which was an answer in itself. Along the river at Grays, Plumstead, and Erith, large bodies of water were found issuing out, some millions of gallons daily. That, he thought, must be the reason why they did not get water under London, as the water skirted London, and found a vent where the chalk was nearly denuded of clay.

Mr. Siebe did not see that the question of the density of the chalk under London could be assigned as a reason for the supply falling off there, for he imagined that chalk was no denser now

Digitized by Google

than it was years ago. For that deficiency there must be some local cause.

Mr. MORRIS said that the chalk under London being covered by the London clay, none of the rainfall penetrated from its surface. It was therefore dependent for its supply on the rain which fell on those parts of the country where the chalk was exposed, and as those were situated at some distance, and water percolated slowly through the chalk, the supply was frequently not equal to the quantity of water pumped. The store of water with which the chalk was at the first saturated, was exhausted, and after a time the well yielded only that small quantity which was able to find its way through the mass of the chalk from the surface which received the rainfall.

Mr. LATHAM, in reply, said that Mr. Glynn had brought forward examples of rain gauges, and had shown the errors to which some of them were liable. His own opinion was that all rain gauges were more or less defective. Thus, in the tumbler gauge a portion of the rainfall might be lost, as a certain amount was necessary to overcome the friction of the machine, and if anything less than that amount fell, it might be evaporated without being recorded. Again, in all gauges there was more or less a loss produced by the adhesion of the water to the surface that first received it; and that portion did not enter the measuring chambers, but was evaporated.

The effect of those errors, when considering the abundance of a supply of water, was rather beneficial than otherwise; but when considering the construction and stability of the works themselves, it would be well to allow for rather greater floods than the rain-gauge would record. The form of rain-gauge had much to do with the accuracy of the results: thus, a rain gauge having a rim inclined inwards, at an angle of 45 deg., was objectionable, as, when the rain was driving at an angle less than a right angle, a certain amount would be thrown into the gauge, and therefore the results would be exaggerated; a gauge having the rim inclined outwards was liable to contrary errors. He believed that a gauge with a pretty deep rim nearly perpendicular was by far the best form; such a gauge would retain in the funnel three or four inches of snow. The applicability of a rain gauge to record correctly in winter, should receive some attention, as many gauges in use were unable to retain anything approaching the quantity of snow falling at the time of a heavy snowstorm. In fixing rain gauges, care should be taken that they were not shaded by trees, buildings, or other things, and that the rim of the gauge was perfectly horizontal.

The infiltration gauge consisted of cylinders of cast-iron filled with earth and chalk. There could not be the slightest doubt

Digitized by Google

but that gauges of that description were liable to very great errors, owing to the inability to construct a gauge that would correctly represent and perform all the functions of the natural surface of the earth; consequently, the materials in artificial gauges were found in course of time to become concreted more or less, and resist the passage of water.

Mr. Morris had drawn attention to the character of the chalk, as being a more or less porous material containing water, but it must not be forgotten that the supply of water to be obtained from chalk would be limited if it were not that that formation was ramified with fissures and layers of flints, forming main ducts for conveying the water into wells.

Attention had been drawn to the lowering of the water level in the London basin, which had been ascribed to the extension of building operations in covering the surface, and of surface drainage; but he did not think that those were the true causes of the lowering of the water level, as the whole basin under London was covered with the dense and impervious London clay; so that, for all practical purposes, the operations carried forward on the surface would have very little effect in leading off any water from the lower basin. The true reason for the lowering of the water line he ascribed to the increase in the number of wells, and to the increased quantity of water taken.

The Chairman, after a few observations on the excellence of Mr. Latham's paper, said that, as regarded rain gauges, there was no doubt that rain gauges which erred on the right side were far better for engineers than those which showed errors upon the wrong side. It was almost impossible to make a rain gauge that would gauge the whole of the rainfall, for there were many things that would prevent the exact amount of the rain being registered. He thought No. 6 gauge would be quite correct enough for all practical purposes. There could be no doubt it was very difficult to gauge the amount of rain that fell over a given district in a given time, simply because rain was sometimes falling heavily in one place and not in another, although in the same district. Therefore, gauges should be placed in different positions at the tops of mountains and the bottoms of valleys. At first sight, Mr. Glynn's remark of the evaporation being 250 per cent more than the rainfall was rather startling, but it was not the kind of evaporation that in a rain gauge was wanted, being the actual evaporation from the ground. If it were wanted to gauge the amount of evaporation, an instrument must be had which would adapt itself to the nature of the soil. A question had been raised as to chalk, which in some cases was exceedingly hard. He might mention that some years ago, when sinking a well at the Crystal Palace, some chalk was bored through, in which there was but a

Digitized by Google

small quantity of water, and when the boring reached such a depth as to be quite through the chalk, there was no water. No doubt, if the chalk was hard, it would contain but little water. In one district water was found in the chalk, but not in another, which showed that the water did not go through the solid chalk; there must be a different character as regarded the pores. It could scarcely be that there were beds of flint, because, if that was the case, if water was supplied to one well it would be supplied to all. There must be a great difference in the porous character of the chalk, or there must be some fissures. And it might be that in each of the supplied wells a fissure was come upon. He believed that the reason why the water in the London wells was at a greater depth than some years since, was, that formerly very little or no water was taken out of the chalk, whereas now so many wells were sunk. It seemed that more water was being pumped than the breaks or fissures in the chalk were capable of supplying. It could scarcely be that London being covered with houses had stopped the supply, because, where the houses were built, there was a large bed of clay. With reference to Mr. Olrick's statement respecting the waterworks at Hull, it was very plain that if river water were used at all, there could not have been a sufficient quantity of the other water for all their requirements.

THE END.

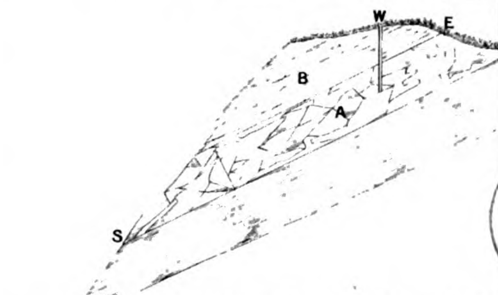
LONDON:
PRINTED BY C. WHITING, BEAUFORT HOUSE, STRAND.

Digitized by Google

Digitized by Google

Fig . 7

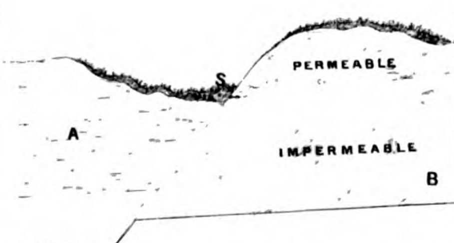
Shewing the causes which sometimes c
limited supply of water in Artesian



Rain descending on the basset E.F *of*
strata A *which lies between the impervio*
will make its appearance in the form of
but such spring will not yield any great
water, as the area E.F *which receives th*
limited in its extent - A well sunk at W
the above description would not be likel
a large supply if any water.

Fig. 8

Shewing the effect of a fa



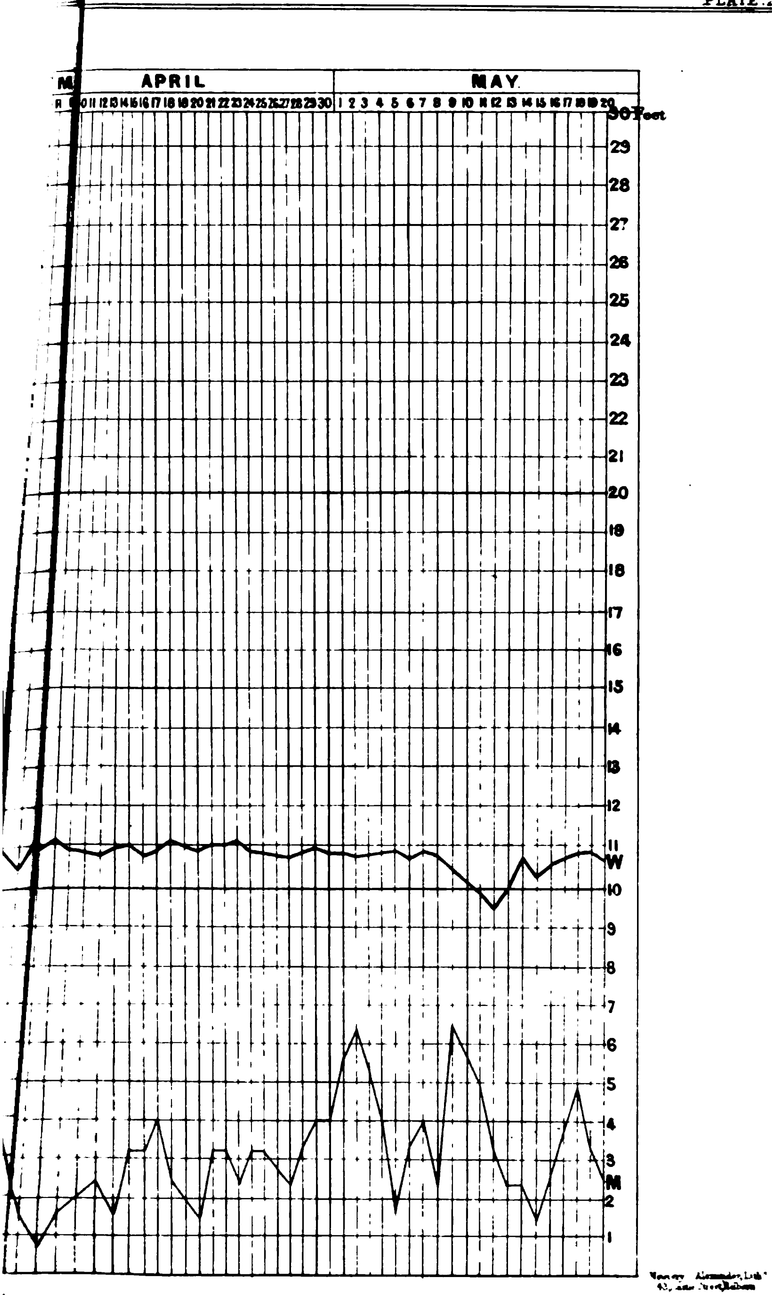
A spring will in all probability make its appear
point S *and such spring will in all probability be*
whole body of water flowing through the porous
intercepted by being thrown against the imperm

Digitized by Google

LIBRARY
OF THE
UNIVERSITY
OF
CALIFORNIA

Digitized by Google

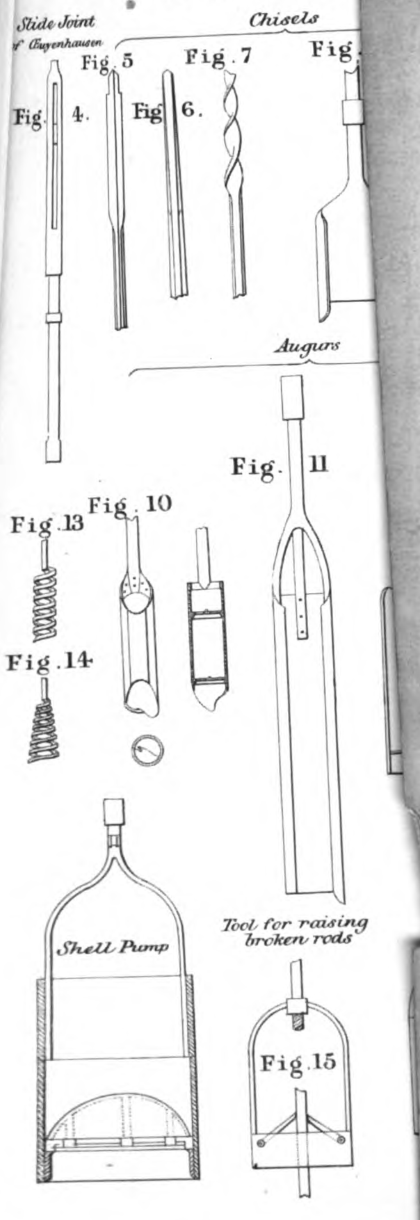
PLATE. 2



Digitized by Google

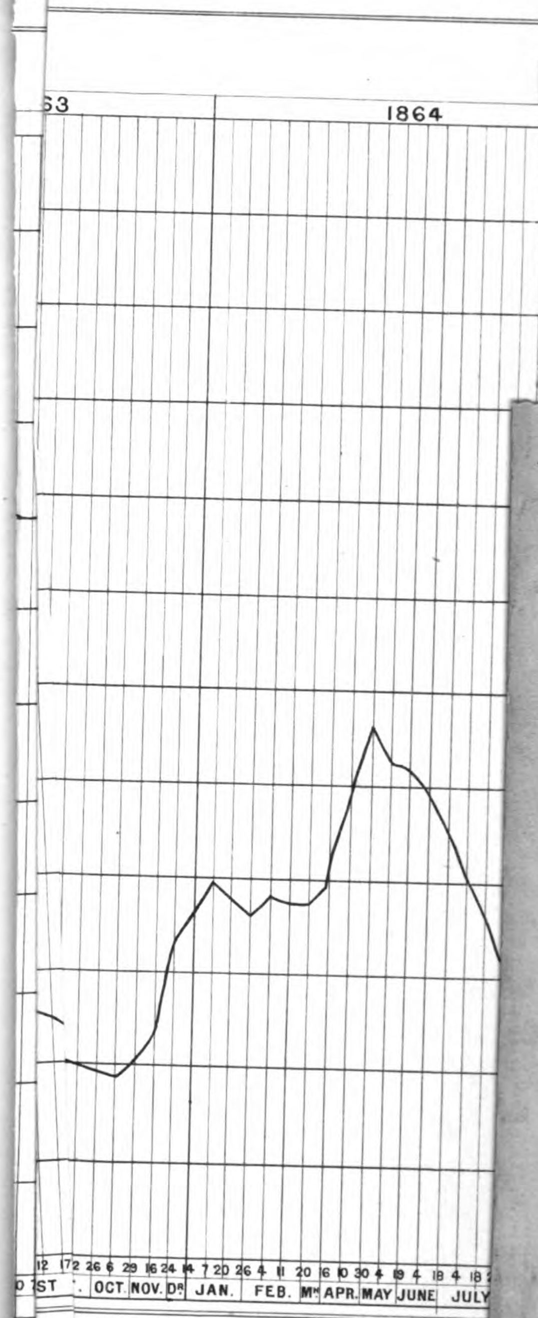
Digitized by Google

BORING TOOLS



Digitized by Google

Digitized by Google


63
1864
12 17 2 26 6 29 16 24 14 7 20 26 4 11 20 16 10 30 4 19 4 18 4 18
ST OCT. NOV. JAN. FEB. APR. MAY JUNE JULY

LIBRARY
OF THE
UNIVERSITY
OF
CALIFORNIA

Digitized by Google

Digitized by Google

LIBRARY
OF THE
UNIVERSITY
OF
CALIFORNIA

4

Digitized by Google

Digitized by Google

Digitized by Google

Digitized by Google

Digitized by Google